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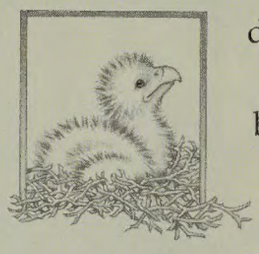

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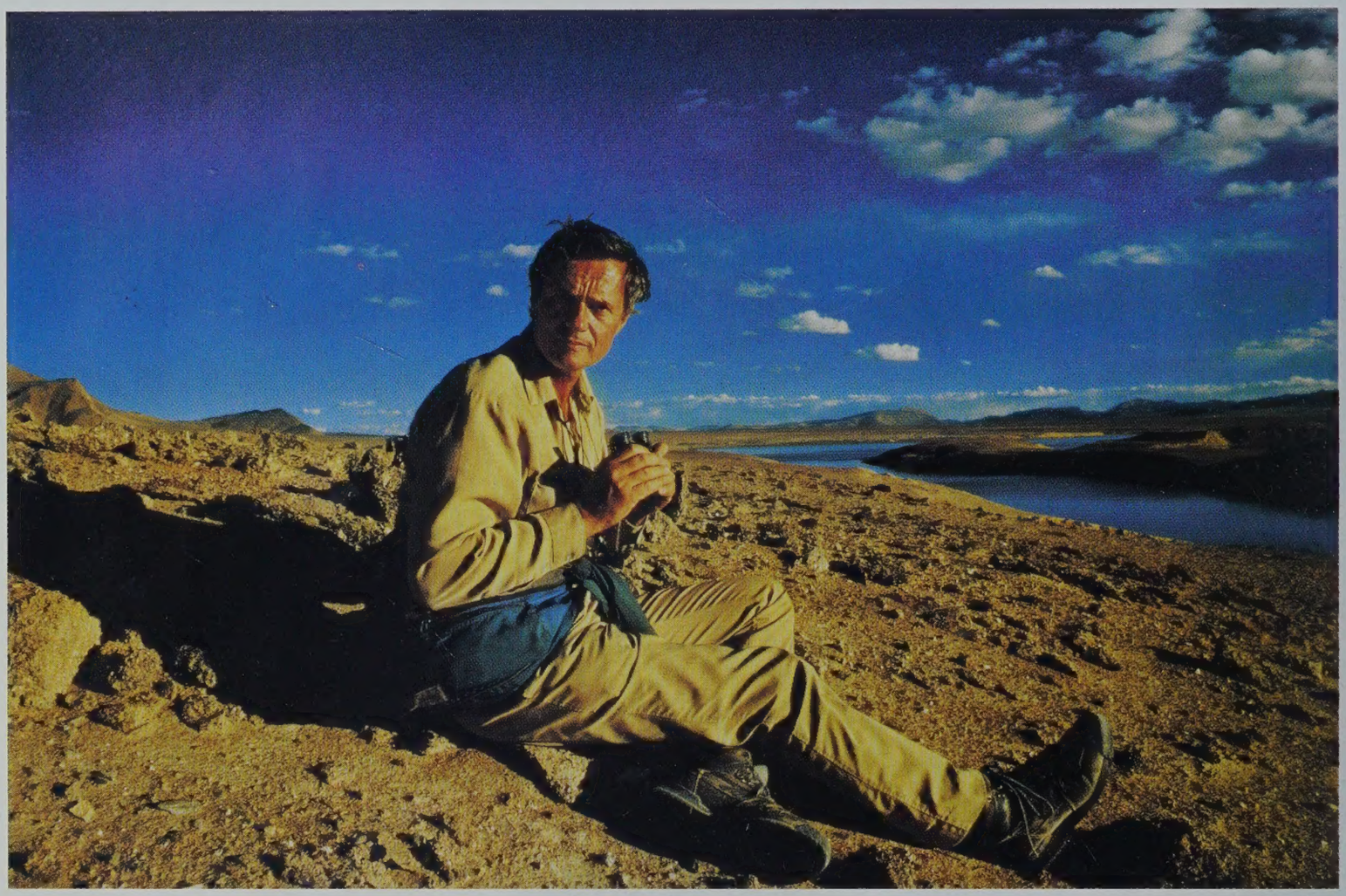

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NATURAL HISTORY

FEBRUARY 2001 VOLUME 110 NUMBER 1

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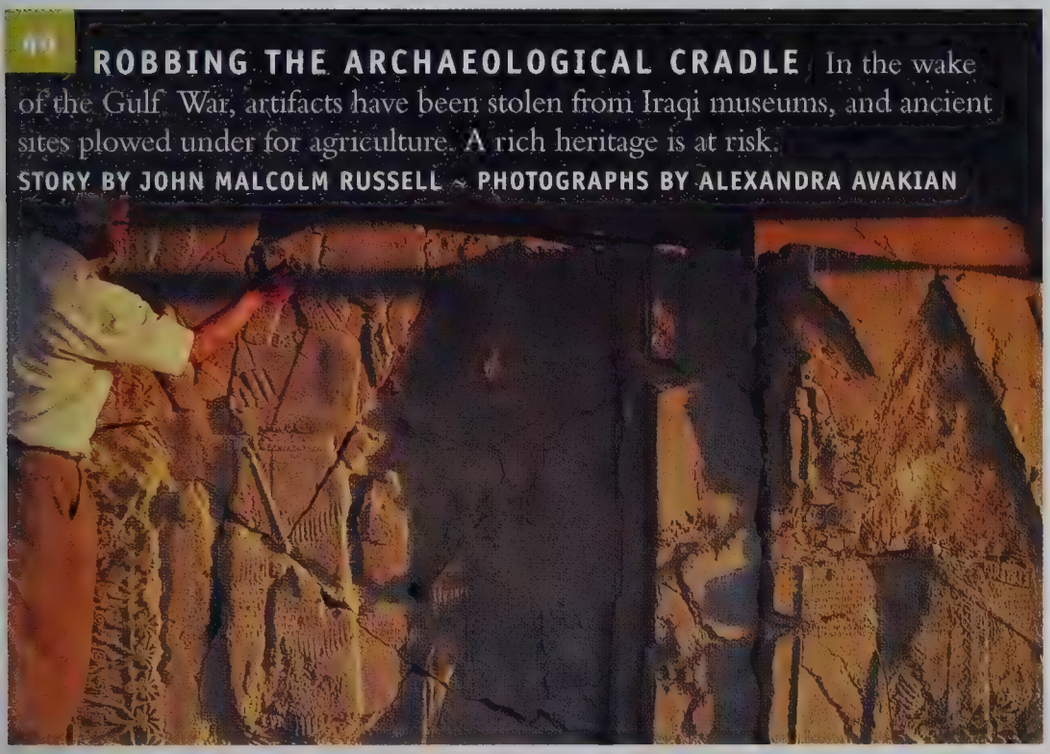

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COVER Purple prickly pear is one of myriad cactus species in Agua Caliente Canyon, Arizona.

STORY BEGINS ON PAGE 26

PHOTOGRAPH BY JACK DYKINGA

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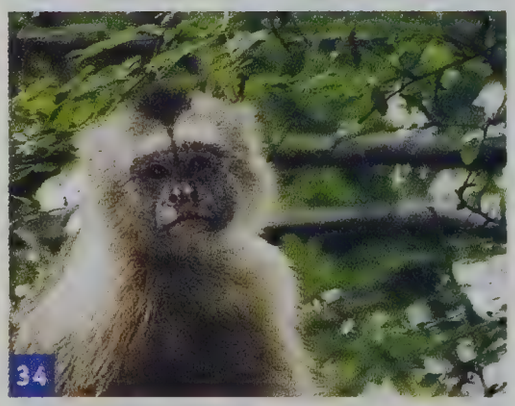

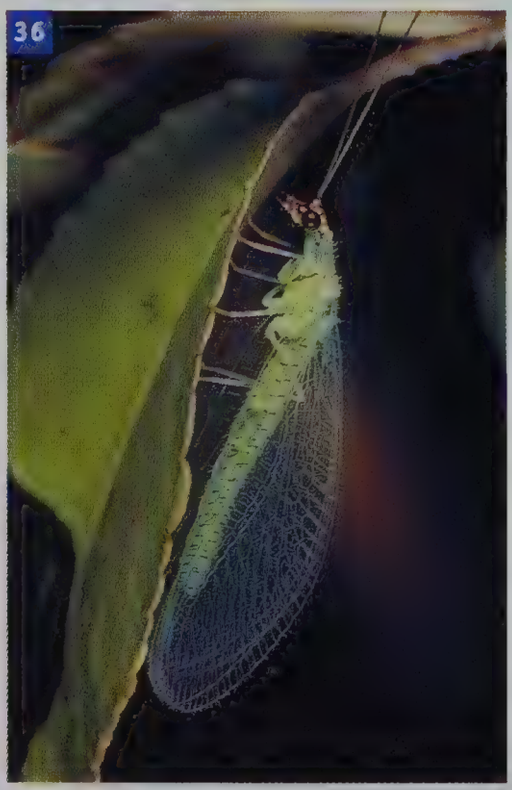

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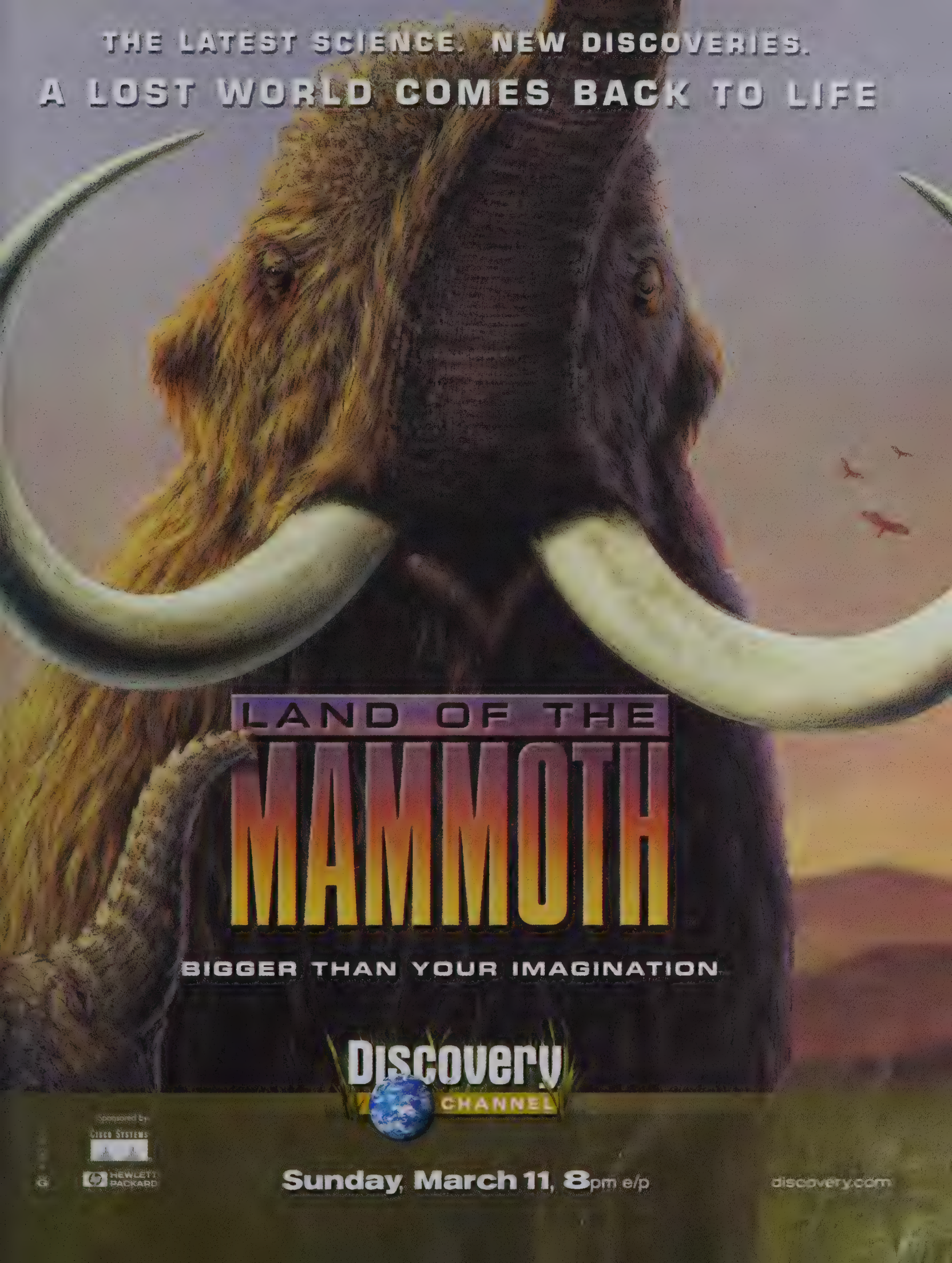
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UP FRONT

Collective Memory

We are all historians, archivists, curators. We paste family photographs into albums or cram them into boxes along with school yearbooks and letters from old friends. We hold on to material objects, however plain, that embody private memories. A few people I know are quite ambitious in their efforts to possess a past that is theirs alone. With some historical detective work, they manage to reconstruct a genealogy, tracing their line back to early colonists or distant shores. Others among us, however, can't peer very far into the family past without losing track of our ancestors, whether in the chaos of minor and major migrations or the tragic oblivion of slave ships, massacres, famines, plagues, and wars.

But all of us leave the chronicling of deep time and large-scale history (the stories of our nations, our ethnic or religious groups, our species itself) to the professionals—historians, archaeologists, paleontologists, and (these days) even geneticists, who trace the winding paths of our genes on strands of DNA. Yet these large-scale stories, together with the irreplaceable historical objects connected with them, belong to all people. In an important sense, a document such as the Magna Carta or the map of the human genome belongs to everyone, as do humanity's artistic and architectural masterworks. Machu Picchu, Luxor, the Parthenon, Angkor Wat, and all the other special places built by our forerunners, while the pride of particular nations, can also be said to be the property of the world.

ALEXANDRA AVAKIAN

Tourists at the site of Babylon's Hanging Gardens

As John Malcolm Russell explains in this month's issue, the land we now call Iraq (known in the past as Mesopotamia, Sumer, Assyria, and Babylonia) is the birthplace of writing, irrigation, cities, religion, monumental architecture, and other major human innovations. Iraq, writes Russell, is one big archaeological site. Certain of the country's ancient places, such as Nineveh and Babylon, are well known; others are obscure and have yet to be fully excavated. During the Gulf War, some sites were severely damaged, and in the years since, many have been critically endangered by looting.

However one views the politics and events that have led us to this point, Russell's article and Alexandra Avakian's photographs serve to remind us that if the special places of Iraq are destroyed or lost, all of us are diminished.—*Ellen Goldensohn*

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LETTERS

Daddy Longlegs

I was delighted by "Touchy Harvestmen" (10/00), by Rogelio Macías-Ordóñez. I will be able to use my newfound knowledge of how the daddy longlegs feels its way through life in my own work as a naturalist. It will help city kids relate to and be less afraid of these gentle creatures. I've been told that daddy longlegs are poisonous but have mouthparts too tiny to inflict wounds in humans. Is this true?

Carolyn Sanford
Clinton, Maryland

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Harvestman

ROGELIO MACÍAS-ORDÓÑEZ REPLIES: Those of us working with daddy longlegs have all heard and been puzzled by that story, as there is no evidence to support it. I polled some fellow biologists, and one explanation was that at some point, an article on a group of somewhat poisonous Australian spiders that are also called daddy longlegs was picked up by the U.S. media, and the creature was interpreted to be our own harvestman daddy longlegs. The colleague who related this also commented that the poisonous harvestman story has become an urban legend and is one of the most commonly asked questions about arachnids. True members of the harvestman order, Opiliones, can produce secretions to which some people may be especially sensitive, but that's all.

Snakes' Breath

Carl Zimmer's article on snakes ("Biomechanics," 11/00) reminded me of a question I've never heard answered. Given that snakes regularly swallow prey thicker than their own bodies, how do they breathe during this process?

Joe Kesselman
via e-mail

BRAD MOON (whose work Zimmer discussed) REPLIES: Snakes can hold their breath for a long time but can also breathe while feeding. These reptiles have one very long lung and one short, vestigial lung. If a snake is using the front of its body to squeeze or swallow a mouse, for example, then it can use muscles in its midsection to help pump air to the long lung. Also, the epiglottis, or opening to the trachea (in the floor of the snake's mouth), can be pushed forward a little and opened to let in air. While a snake is ingesting prey, it will periodically stop its jaw movements to stick out the epiglottis and breathe.

Serpent Encounters

J. Alan Holman's article ("Endpaper," 11/00), in which he mentioned the smooth green snake, was of special interest to me because I had seen one of these little gems of the serpent world just a couple of weeks earlier. On an exceptionally warm fall day, my wife and I went for a walk at a nature preserve, a mixed area of open sphagnum bogs and glacially derived sand dunes, now overgrown with white pine and hardwoods. No less than five snakes—four garter and one smooth green—crossed our path that day.

I had last seen a smooth green snake fifty years ago. At the time, I was staying at a farm in northwestern Pennsylvania owned by the uncle of a friend. The uncle had yelled at my friend and me just the day before for releasing a large snake that we had found near the house. His exact words were "I don't care how big a snake it is, I want you to kill it." Even after his reprimand, I was so entranced by the smooth green snake that I captured it, placed it in a small box, and kept it secretly in the farmer's home until I was able to leave on the bus with the snake hidden in my luggage. I kept it in an aquarium for several weeks and fed it insects. Eventually I released it in my own neighborhood.

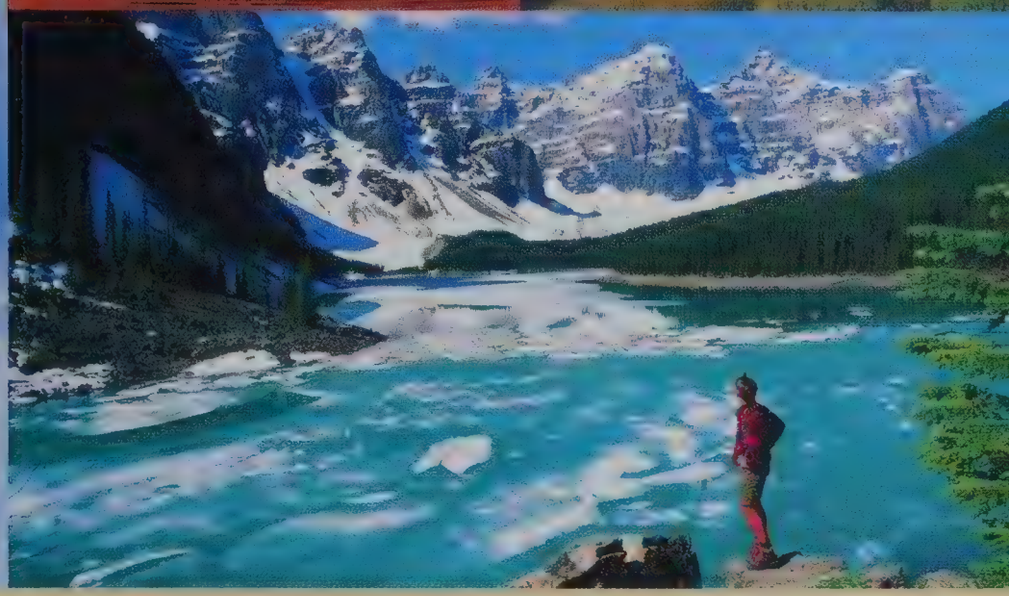
Roy H. Senn
Rome, New York

Celestial Names

In "Celestial Events" of 11/00, on the naming of recently discovered celestial bodies, author Richard Panek mentions only names from Western cultures and none from peoples elsewhere in the world. The International Astronomical Union should be pressed to name some percentage of newfound features using terms from the astronomies of peoples of Africa, the Middle East, Latin America, the Pacific, Australia, and Asia.

Allen F. Roberts
Los Angeles, California

RICHARD PANEK RESPONDS: The brevity and limited scope of my article made references to non-Western cultures impractical, but you will be glad to know that other cultures are indeed well represented in the names of new celestial bodies. Just a cursory look at the first page of the International Astronomical Union's list (wwwflag.wr.usgs.gov/nomen-bin/search.cgi) of



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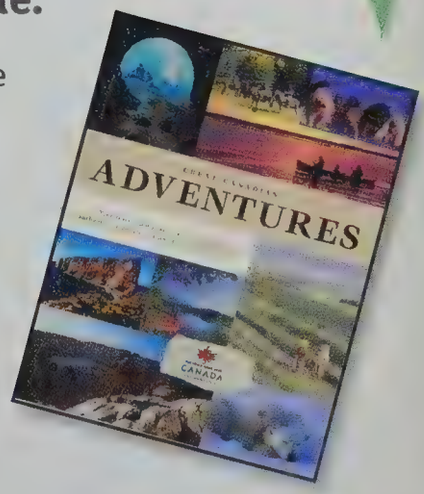

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nomenclature approvals for 2000 turns up a Mayan name for morning Venus and features named for a gigantic Egyptian serpent, a Talysh (Caspian Sea) river deity, a Sumerian thunderbird, and a Quechua potato goddess. There are thirteen more downloadable pages that include names from Aztec, Australian Aboriginal, Indonesian, Sioux, Polynesian, Madagascan, Vietnamese,. Tibetan, and other cultures.

Double Your Pleasure

Neil de Grasse Tyson's account of geometric progression ("Universe," 11/00) reminded me of two early legal cases in England that also teach this lesson well. In 1661 James sued Morgan for their agreed-upon price of a horse: one barleycorn for the first nail in its shoes, doubled successively for each of the other thirty-one. Morgan must have been dumbstruck upon learning that he owed nearly 4.3 billion barleycorns, but the judge directed the jury to decide upon a fair value for the horse, which it set at eight pounds. Several decades later, Thornborough gave Whitacre a half-crown in exchange for a grain of rye that was to be doubled in number each week for a year. The judge knew this would be "a vast quantity" and thought the jury would "consider the folly of the defendant" and award a reasonable amount, but the parties settled before trial when the grateful Whitacre offered to return the half-crown and to pay Thornborough's legal costs. The judge was right, of course. This vast quantity of 4.5 quadrillion grains, or 4.4 billion bushels, was about 540 times the total amount of rye harvested in the United States in 1997.
William (Tom) Thomas
Oak Ridge, Tennessee

Setting the Banding Record Straight

The article by Annette Heist on song learning in hummingbirds ("Singing in the Brain," 10/00) offered a fascinating glimpse into a little-known part of the lives of these familiar birds. However, as an ornithologist and bird bander whose specialty is hummingbirds, I was surprised to read the author's assertion that hummingbirds cannot be banded due to risk of injury and impaired flight.

I'm happy to report that the 3,000-plus hummingbirds that I've handled as part of studies here at the Southeastern Arizona Bird Observatory appear quite comfortable wearing their specially made bands and have absolutely no trouble flying with these minuscule aluminum rings around their legs. In fact, some of my avian acquaintances have worn their bands for as long as eight years with no apparent ill effects, racking up thousands of frequent-flyer miles on their annual migrations and nesting up to three times per year.

Admittedly, banding hummingbirds is a research specialty. Of approximately 4,000 licensed banders in the United States, less than 3 percent are permitted to band hummingbirds. As with our other native birds, hummingbirds are banded with the permission of, and using numbered bands issued by, the Bird Banding Laboratory, a division of the U.S. Department of the Interior.
Sheri Williamson
Bisbee, Arizona

ANN AND ROB SIMPSON
Banded hummingbird at feeder

THE EDITORS RESPOND:
Every article in the magazine is a collaboration and reflects the effort and input not only of the author but also of scientists and editors. The error that you and other dedicated banders pointed out originated in a misinterpretation of information from an ornithology lab. But the failure to scrutinize the statement was ours. We thank you for your enlightening letter.

Drawing Water

Carl Zimmer's discussion of Barbara Bond and Michael Ryan's work on the natural limits to tree height ("Biomechanics," 10/00) left me wondering about one thing: After a tree drops its leaves in the fall, how does the process get started again in the spring? Without any active stomata to draw up water, how do the buds get enough water so they can open into leaves?
Van L. Knowles
Lexington, Kentucky

BARBARA BOND REPLIES:
This is a great question. Cells in buds are alive through the winter. In spring, light and temperature patterns send signals to the buds to begin converting their stores of starches into sugars, creating high osmotic potential in the cells. Water then moves into the cells by osmosis. As the water arrives in the cells, it increases the "tension" of the water in the buds surrounding the cells, causing water to be pulled up from the roots.

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Mention social insects and most people tend to envision a beehive or a termite mound, not a white globe housing a contingent of caterpillars. Entomologist **Terrence D. Fitzgerald** ("The Nightlife of Social Caterpillars," page 38) has spent much of his professional life documenting the ecology of butterfly larvae that live in colonies. A professor of biology at the State University of New York College at Cortland, Fitzgerald teamed up in 1996 with Dessie Underwood (now at the University of California, Davis) to study the colonial, cold-adapted madrone caterpillars of Mexico's Sierra Madre Occidental. For the 4/95 issue of *Natural History,* he wrote "Caterpillars Roll Their Own," on leaf-rolling caterpillars.

Art historian **John Malcolm Russell** ("Robbing the Archaeological Cradle," page 44) has witnessed some of the ways in which Iraq's heritage has been lost following the Gulf War. While excavating in 1989 and 1990 at Nineveh, he photographed sculptures from the palace of the Assyrian king Sennacherib, a monarch whose exploits are recorded in the Bible. In 1995 he was shown many of the same sculptures, but by then plunderers had cut them up to sell piece by piece on the antiquities market. An associate professor of art history and archaeology at the Massachusetts College of Art in Boston, Russell is the author of *The Final Sack of Nineveh* (Yale University Press, 1998). Photojournalist **Alexandra Avakian** has worked in the Middle East, eastern Europe, central Asia, and Africa for such publications as *National Geographic, Time, Life,* and the *New York Times Magazine.* She thought that a story on the state of Iraq's archaeology would be a fresh way to address the impact of sanctions on that country and its people. On a couple of occasions she had to work during sandstorms, which, she concluded, gave her photographs an appropriately moody feeling. In particular, she liked photographing villages near the sites, knowing that they had been there, in some form, for thousands of years.

A professor of evolutionary biology at Australia's University of Sydney, **Richard Shine** ("Serpentine Cross-Dressers," page 56) has studied pythons in Australia and pit vipers in China. Shine (at right) earned a doctorate at the Australian National University with a dissertation on venomous snakes and a second doctorate in reptile ecology at the University of Sydney. Coauthor **Robert Mason,** an associate professor of zoology at the University of Oregon, discovered the "she-male" phenomenon in garter snakes while in graduate school. He met his future wife, Sarah, when she came to Manitoba as a volunteer at the province's snake dens. "Not too many people," he writes, "can say they met their spouse in a snake pit with 25,000 mating garter snakes swarming around their feet." For more on garter snakes, Mason and Shine recommend *The Snake Scientist,* by Sy Montgomery (Houghton Mifflin, 1999), with photographs by Nic Bishop.

Richard W. Burkhardt Jr. ("A Man and His Menagerie," page 62) has spent many happy hours at the National Museum of Natural History in Paris—years ago, while studying French biologist Jean-Baptiste Lamarck, and more recently, while researching the history of animal behavior studies. The key figure in his later research proved to be Frédéric Cuvier, the younger brother of Lamarck's rival on evolutionary matters, Georges Cuvier. A professor of history at the University of Illinois at Urbana-Champaign, Burkhardt is the author of *The Spirit of System: Lamarck and Evolutionary Biology* (Harvard University Press, 1977) and is now finishing up a book on the establishment of ethology as a scientific discipline in the twentieth century.

Paul Nicklen ("The Natural Moment," page 84) was raised in a tiny Inuit village on Baffin Island and has spent most of his life in Canada's far north. Trained in marine biology at the University of Victoria, he spent several years as a government wildlife biologist in the Arctic. Nicklen, who says he tries "to photograph stories rather than just take pleasing pictures," has snowmobiled 4,000 miles through the Arctic archipelago in search of polar bears and swum among seventy-ton bowhead whales in the Arctic Ocean. His work has appeared in *Natural History, Terre Sauvage,* and *Life.* Nicklen's latest book of photographs is *Seasons of the Arctic,* in collaboration with Hugh Brody (Greystone/Sierra Club). He lives in Whitehorse, Yukon.

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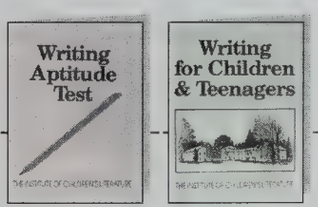

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BIOMECHANICS

The Perfect Limpet

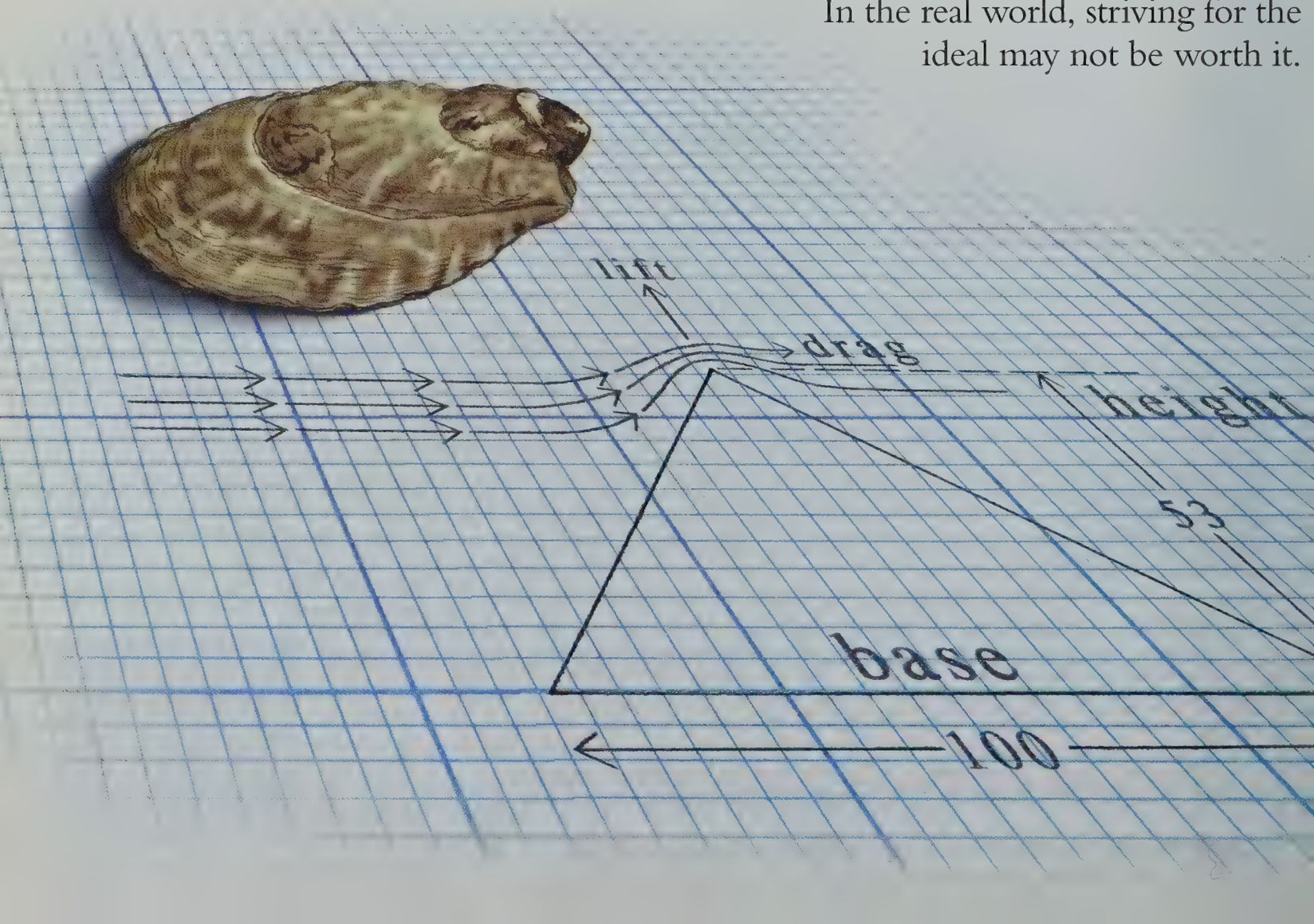
In the real world, striving for the ideal may not be worth it.

Story by Carl Zimmer ~ Illustration by Sally J. Bensusen

It would seem axiomatic that well-designed animals outperform badly designed ones and pass on to their offspring the genes that helped create that design. As good genes arise and spread, animal designs should theoretically shift from the flawed toward the better. So when a design is significantly inferior to what might seem best for a given situation, something interesting is probably going on. Stanford University's Mark Denny recently investigated one such apparently poor design—that of the limpet.

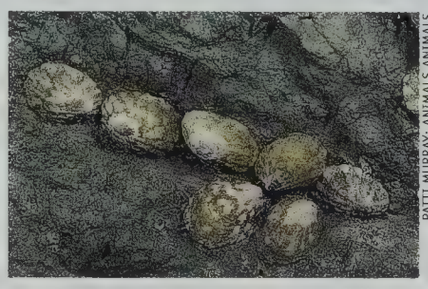
Limpets are marine gastropods that live on rocky coasts and in tide pools. They excrete a gluelike substance to anchor themselves to rocks but can loosen their grip enough to slide around on their single "foot" and graze on algae. The limpet's shell, a low cone that looks like a gently sloping hill, provides protection from crabs, birds, and other predators. It also helps the animals survive the waves that regularly slam against them at speeds greater than eighty feet per second.

The shape of a limpet's shell has a great deal to do with whether the animal remains securely attached to its rock or is ripped off and thrown onto dry land or into the waiting tentacles of a hungry sea anemone. There are two ways a wave can dislodge a limpet. If the limpet's shell is steep-sided, the



drag of the water against the sides of the shell will force it in the direction of the wave. But if the limpet has a rounded hump, the water may pull it off its rock in the following way: The presence of the limpet creates an interruption in the onrush of the wave, "squeezing" the water over the rounded top of the shell and forcing it to move faster, which lowers its pressure. Water flowing around the base of the shell moves more slowly, raising the pressure. This water pushes against the limpet under its shell, producing high pressure in its body as well. The difference in pressure—high beneath the shell, low above it—can create enough lift to suck the limpet right off its rock.

To measure the drag and lift experienced by limpets, Denny put acrylic models of their shells in a wind tunnel. (Technically, air and water are both fluids, and as such, they both flow. Air may be 800 times less dense than water, but it is easier to work with experimentally.) Some of the models had small holes to which Denny attached sensors that measured how pressure was distributed over the shell. Other models were rigged up with springs at their base to measure how much drag the wind imposed on them. And Denny tried out a range of different shell shapes—some with high peaks, some with low ones, some with central peaks, and others with peaks set off to one side.



PATTI MURRAY; ANIMALS ANIMALS

Mask limpets *(Tectura persona)*

Studying his results, Denny figured out the specifications for the perfect limpet shell: to get the best protection against the combined dangers of lift and drag, a shell's height should be 53 percent of its length and its peak should be directly over the center of its shell. Yet real limpets are a long way from perfection. Most of them are fairly squat, with an average height-to-length ratio of only 34 percent. Seemingly making matters worse, their peaks are generally well off center.

To understand why limpets have such an imperfect design, Denny switched from the ideal to the real, making a close study of the owl limpet, *Lottia gigantea*. Found along the California coast, the owl limpet can reach up to four inches in diameter. Its height-to-length ratio is an embarrassing 25 percent, and the peak of its shell is perched at its front end. Pugnacious, it pushes away other limpets that trespass on its little patch of rock. However, faced with certain predators, such as starfish, it lifts up its shell and slides away as fast as it can—at a speed of one inch per second. On the rocky coastline near his lab, Denny measured how much force it took to pry a limpet off a rock. He also lassoed limpets with a loop of string and tugged on them to gauge how well the shells withstood drag.

Denny found that the most important factor determining whether a limpet gets washed away or not is how tightly glued to the rock it is. If an owl limpet is hunkered down when hit by a wave moving at eighty feet per second, it has a 91 percent chance of holding fast, but if it has the bad luck to be running away from a starfish, it has only a 0.5 percent chance of not being washed away. An optimal shell design doesn't change the odds very much: a perfect owl limpet would have a 95 percent chance of holding fast if it was anchored, a 2.4 percent chance if it was on the go.

The minor risk posed by the owl limpet's shape is probably offset by the advantages. The off-center peak of this creature's shell allows the limpet to use it like a bulldozer to clear its territory of other animals. Fewer competitors mean more food, which may ultimately translate into more baby limpets. And together with the strength of its glue, the limpet's habit of hunkering down when big waves start pounding its rock may help compensate for its "poor" design.

Like engineering, biomechanics is all about trade-offs. But nature has a special set of trade-offs that human engineers don't have to worry about—when designing skyscrapers, they can be reasonably sure that other skyscrapers aren't going to move in and try to push theirs off the block.

Science writer Carl Zimmer is the author of At the Water's Edge *and* Parasite Rex.

For a limpet, the best way to avoid being swept from a rock by powerful waves is to have a shell with a height 53 percent of its length and a peak directly over its center. In reality, however, most of these mollusks, like the owl limpet at left, make do with a squat shell and an off-center peak.

NATURE'S INFINITE BOOK

A Tale of Two Reputations

Why we revere Darwin and give Freud a hard time

By Jared Diamond

We scientists have fantasies of being uniquely qualified to make great discoveries. Alas, reality is cruel: most of us are replaceable. For the vast majority of scientific contributions, if scientist X hadn't achieved it that year, scientist Y would have achieved the same result or something very similar soon thereafter. In modern molecular biology, most famous discoveries emerged as multiple teams raced toward the finish line, with the "loser" only a few months behind the "winner." For instance, if James Watson and Francis Crick hadn't published the correct structure of DNA on April 25, 1953, Linus Pauling, who was working on the same problem and had just published an incorrect structure, would surely have arrived at the correct answer within a short time.

Have any individuals really made a major, lasting difference to the course of science? More specifically, would their discoveries or conceptualizations have eluded other scientists until decades later if these individuals had not been born, and did their contributions have a unique impact that persisted long afterward? By those two criteria, I think that only two scientists within the last two centuries clearly qualify as irreplaceable: Charles Darwin and Sigmund Freud. (I feel unsure whether Albert Einstein's impact was as far-reaching.) A comparison of Darwin and Freud proves interesting. What made them irreplaceable, what exactly did they get right, what did they get wrong, how similar were their personalities and their peer relations, and how do their reputations compare today?

To begin with, Darwin and Freud were both multifaceted geniuses with many talents in common. Both were great observers, attuned to perceiving in familiar phenomena a significance that had escaped almost everyone else. Searching with insatiable curiosity for underlying explanations, both did far more than discover new facts or solve circumscribed problems, such as the structure of DNA: they synthesized knowledge from a wide range of fields and created new conceptual frameworks, large parts of which are still accepted today. Both were prolific writers and forceful communicators who eventually converted many or most of their contemporaries to their positions. (In this, they were unlike Gregor Mendel, the founder of genetics, who within his lifetime convinced nobody of the significance of his discoveries.)

Both made their contributions as a result of new insights, not as a result of inventing a new instrument or technology. In fact, both used little more than their eyes and ears. One must therefore pause to wonder why Darwin's views on evolution, and Freud's on the human mind, had not already been formulated by Aristotle and the ancient Greeks. The answer is that the views of both depended on the enormous amount of knowledge that had accumulated over the two millennia since Aristotle's time—not only discoveries about natural history and the human mind but also a developing framework of concepts and questions (what historians describe by the German word *Fragestellung*).

DRAWINGS BY DAVID LEVINE

Charles Darwin

Darwin's contributions came at a time when almost everyone (including scientists) believed in the divine and independent creation of species, and when scientists were recognizing patterns in the burgeoning discoveries about fossils, taxonomy, and biogeography but still lacked explanations for those patterns. Today Darwin is best known for establishing the fact of evolution and for recognizing the major role of natural selection in driving it. Actually, he achieved far more than those two most famous of his contributions. He also recognized sexual selection as an additional evolutionary driving force, laid the foundation for today's understanding of animal behavior, published a major work on the behavior and physiology of insectivorous plants, and provided the correct explanation for hierarchically branched taxonomies as well as for the origins of biogeographic regions, coral reefs, volcanic rocks, and soils. Underlying Darwin's contributions were his very broad technical competencies in anatomy, botany, embryology, geology, paleontology, taxonomy, and zoology, as well as his threefold methodological brilliance as an observer, experimentalist, and theoretician.

In his mastery and synthesis of many types of information and his ability to utilize diverse approaches, Darwin was unique. No biologist then or since has come even close to matching him, and that's why no one else made his contributions. While it is true that Alfred Russel Wallace and Darwin independently came up with the idea of natural selection and evolution, the reasons that Darwin, not Wallace, is regarded as the irreplaceable genius are instructive. Wallace's reasoning about natural selection, and the initial evidence he based it on, were essentially the same as Darwin's. But the papers about natural selection by Wallace and Darwin that the Linnean Society published side by side in its journal in 1858 were ignored. The world did not begin to be convinced of natural selection until Darwin published the *Origin of Species* a year later, making an overwhelming case by amassing evidence from many fields. Because Wallace lacked depth in many of the disciplines and approaches mastered by Darwin, Wallace could never have made the overwhelming case that Darwin did, and he frequently acknowledged Darwin's greatness thereafter.

Freud's contributions came at a time when interest in mental illness and its classification was growing but its etiology was virtually unknown and treatments were mostly ineffective—in part because clinicians and researchers were still focused on conscious, cognitive processes. Freud's status is unique because he recognized an entirely different mental realm, and many of his concepts—pioneering and radical in their time—are so familiar today that they have entered the daily vocabulary of the general public. These include the idea of the unconscious, the significance of dreams, the lingering importance of early childhood experience, the Oedipus complex, motivational conflict, and defenses such as denial, rationalization, and repression. For some mental conditions, Freud also devised therapies based on the "talking cure" rather than just on the then-prevalent treatments of electric shock, hypnosis, or institutionalization. He also developed a unifying theory of the normal personality, recognized transference and countertransference in the patient/therapist relationship, and ex-

Multifaceted geniuses, Darwin and Freud were keen observers, perceiving in familiar phenomena a significance that escaped everyone else.

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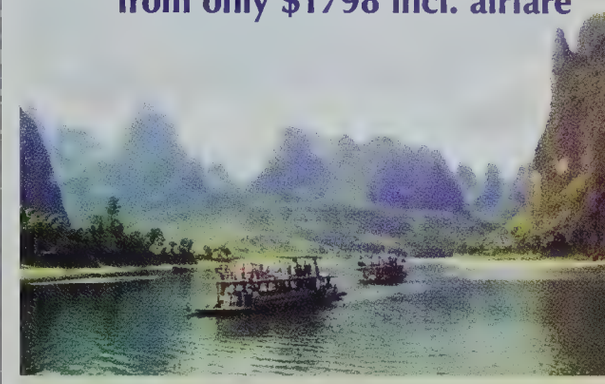

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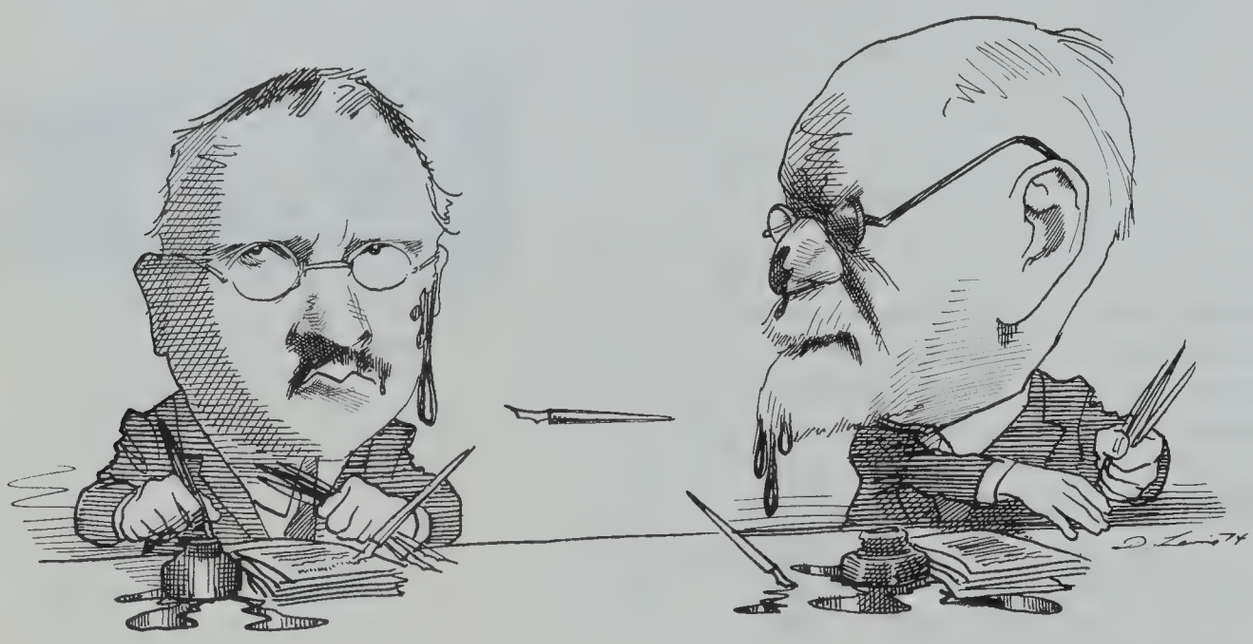
plored the broader social consequences of individual psychopathology.

Freud searched constantly for the underlying causes of mental disorders, and he developed techniques such as free association and the study of dreams to probe the unconscious. As with Darwin, Freud's immense contributions arose from the breadth of his competence—in anatomy, neurology, pharmacology, philosophy, physiology, and psychology. More than just a psychologist who wanted to understand what makes people tick, Freud also had the therapeutic goals of a physician who wanted to help people. Like Darwin, he had no contemporaries whose contributions approached his in scope and originality; there was not even the equivalent of a Wallace to be mentioned and explained away.

Those are some of Darwin's and Freud's successes. What about their omissions and failures? Given their achievements, it may seem absurd even to bring up the issue. This question reminds me of a cartoon of some cavemen pointing to another caveman and asking, "What's that guy done since he invented fire?" Of course they were limited by the technology of their time: one can hardly fault Darwin for not anticipating by a century the recognition of DNA as the genetic material, or Freud for not determining chemical structures and the role of neurotransmitters.

Nevertheless, we still can't help wondering about some things that Darwin and Freud might have recognized or might have gotten right but didn't. Darwin's foremost omission was his failure to progress in elucidating the principles of genetics. Such progress potentially lay within his grasp, because he designed and executed brilliant experiments with plants and published a whole book on cross-pollination and self-pollination. Similarly, the results of his many experiments in pigeon breeding might readily have suggested to him the concept of recessive and dominant traits. Yet Darwin failed to extract the fundamental genetic insights that Gregor Mendel extracted by planting peas during the years just before and after Darwin was writing the *Origin of Species.*

Darwin also got some big things wrong. He shared the then-widespread belief in "soft inheritance," the assumption that the environment could cause adaptive changes in the hereditary material, but his younger contemporary August Weismann showed that this could not be so. Darwin accepted the postulate of "blending inheritance" (the fusion of a mother's and father's characteristics in their offspring), even though his own experiments on pigeons refuted it. Much more surprising are two other errors: he eventually failed to acknowledge the reality of species as non-interbreeding sets of populations, and hence he also eventually failed to accept that new species originate predominantly through geographic isolation, although that precise issue underlies the title of his most famous book. What makes the latter two errors so striking is that Darwin had previously formulated both ideas correctly but then abandoned his formulations in later editions of the *Origin*. These mistakes had long-lasting consequences, because they were not rectified by other biologists until about eighty years later and because a significant minority of biologists persist in those errors today.



Carl Jung

Sigmund Freud

Freud also made some disconcerting omissions and errors. He was a man of his time in some of his views of women; he believed, for example, that a woman's main and appropriate role was that of wife and mother. Rooted in an era that tabooed discussions of sex, he rebounded to the opposite extreme and exaggerated the roles of sex and sexual conflict in the development of the psyche. He gave insufficient credence to some patients' reports of being sexually abused as children. His emphasis on a death wish is now viewed as wrong or greatly exaggerated. At least in part because his driving motivation was to help and to cure people, not just to understand them intellectually, he was not scientifically rigorous. And as a therapist, Freud

could be faulted for not departing from his focus on individuals to develop therapy for couples, families, or groups.

Today we seem much more inclined to castigate Freud for his omissions and errors than Darwin for his. I suspect that there are two reasons for our differing attitudes toward these two pioneers. One is that Freud's failures, unlike Darwin's, have had a direct impact on the lives of individual human beings. Most of us don't suffer as a result of Darwin's having eventually attributed too much scope to the process termed sympatric speciation than it actually deserves. But a powerful man's mistaken ideas about women have certainly caused suffering, just as victims of child abuse have been made to suffer when the reality of their trauma has been denied.

The other reason we are inclined to judge Freud more harshly than Darwin is that these two scientists were near opposites in their relations with peers. In this regard, we find much to admire in Darwin and much to deplore in Freud. Darwin was outstandingly generous in crediting others—including, most notably, Wallace—for their work. While Darwin came in for severe criticism from other scientists and in turn often expressed his disagreement with their views, he responded courteously, used scientific arguments, and completely avoided personalizing disputes. I can think of no one about whom he expressed hatred or said nasty things, and no one whom he tried to impede professionally. Freud, on the other hand, was outstandingly ungenerous: he denied credit to others, was intolerant of rivals, hated many people, and surrounded himself with unquestioningly loyal admirers. Freud's fallings-out with his famous psychoanalytic contemporaries Alfred Adler, Josef Breuer, Carl Jung, and Otto Rank are merely the most notorious examples. A legacy of this aspect of Freud's personality has been the ugly tendency among psychotherapists, especially those closest to the Freudian tradition, to personalize disputes and to break into factions.

Darwin was generous in crediting other scientists. Freud was intolerant of rivals and surrounded himself with unquestioning admirers.

Both Darwin and Freud have had their detractors, and the ideas of both men initially faced fierce opposition. Today very few scientists hold low opinions of Darwin, either as a person or as a scientist. The overwhelming majority of those who fundamentally disagree with Darwin's findings today

are not scientists at all, but creationists, who do not engage seriously with the facts of biology. Virtually no contemporary scientists believe that Darwin was basically wrong. Since Darwin's time, we have of course discovered masses of new facts, formulated new concepts, and advanced beyond many of his specific interpretations, but modern biologists still consider themselves to be Darwin's intellectual descendants, working within his tradition.

By contrast, Freud's detractors remain numerous, even though they take for granted many of his concepts and contributions. Just consider how the Library of Congress's 1998–99 exhibition on Freud in Washington, D.C. (which has since traveled to major museums worldwide) triggered demands by serious thinkers that negative views of Freud be represented. There were protests that Freud was unworthy of even being honored by an exhibition. A corresponding exhibition on Darwin would have been protested only by creationists. I acknowledge a legitimate moral base underlying such Freud-bashing: the human consequences of his scientific errors, and his often ugly interpersonal relations.

Freud's errors, unlike Darwin's, have the potential for direct, damaging impact on the lives of individual human beings.

But there are two other types of Freud-bashing that are not defensible. One consists of pointing out all the new things learned and all the new therapies devised since Freud, as if these represent his failures or demonstrate the uselessness of his work. Yes, we now know much more about how people think and how to help them than we did in Freud's day. But just as with Darwin, that subsequent progress began with Freud's insights and would have been unthinkable without them.

The other type of Freud-bashing—much more damaging because it hurts patients—comes from a too-narrow focus on biological psychiatry. I fully accept the importance of biological psychiatry, having devoted some of my own research to problems in that area (neurotransmitters and manic-depressive illness). It has now become clear, as it could not have been in Freud's day, that some major thought and mood disorders have a biological basis, even though the details of that basis in the most widespread syndromes (depression, manic-depressive illness, schizophrenia, autism) remain elusive.

Many medical-school psychiatry departments were once bastions of Freudian psychoanalysis, whose practitioners resisted biological studies. But now the pendulum has swung to the opposite extreme: psychiatry departments have become bastions of molecular biology, at which much more time is devoted to studying and teaching psychopharmacology than to what are called talk therapies. Outside academia, however—among clinical psychologists, social workers, and lay analysts—those therapies are a growth industry. Among the many reasons for academe's imbalance are its reductionist bias and its professional reward system: many Nobel Prizes and National Institutes of Health grants are available for biochemical research, but many fewer NIH grants and nary a Nobel Prize for talk therapies. Other considerations are that contemporary Western societies tend to seek technological fixes, and health insurance companies are more willing to reimburse claims for drugs than for talk therapy. Certainly, it would be less painful for both therapists and patients if our problems could be solved by taking pills rather than accepting responsibility for our suffering and then learning new ways of interacting with others. Not only that, but the stigma of "mental illness" and the challenges of moral responsibility would be diminished if one's problems arose from chemical processes beyond one's control (as is true in some cases) rather than from voluntary actions.

To my mind, academe's swing away from talk therapies is tragic. Major advances are still being made in this field—for instance, in crisis counseling and in child and family therapy. Almost all of us face stress in our jobs, our health, our personal relationships, and our own aspirations. Almost all of us carry emotional and cognitive baggage from our early lives that leaves us with some inappropriate responses in our lives as adults. Some of those problems can be dealt with by talking with friends. But some problems require professional distance, experience, and skills—the skills in which a talk therapist is trained and that are far beyond the capacity of a friend to deliver.

Even specialists in biological psychiatry need thorough training in talk therapies, because it can be difficult to figure out whether a patient's problems have a primarily biological or a primarily nonbiological basis. Even clients whose problems are probably fundamentally biological (such as in manic-depressive illness) tend to have associated psychological issues that need attention. Physicians who rely heavily on prescribing drugs often don't take time to establish a relationship with a patient, regularly forget that the patient and physician are locked in an emotionally charged relationship, and then are surprised at how often patients fail to take the drugs prescribed for them. Understanding that unique two-way relationship was one of the many deep and far-reaching insights that put Freud right up there with Darwin.

Jared Diamond is a professor of physiology at the UCLA School of Medicine and a research associate in ornithology at the American Museum of Natural History.

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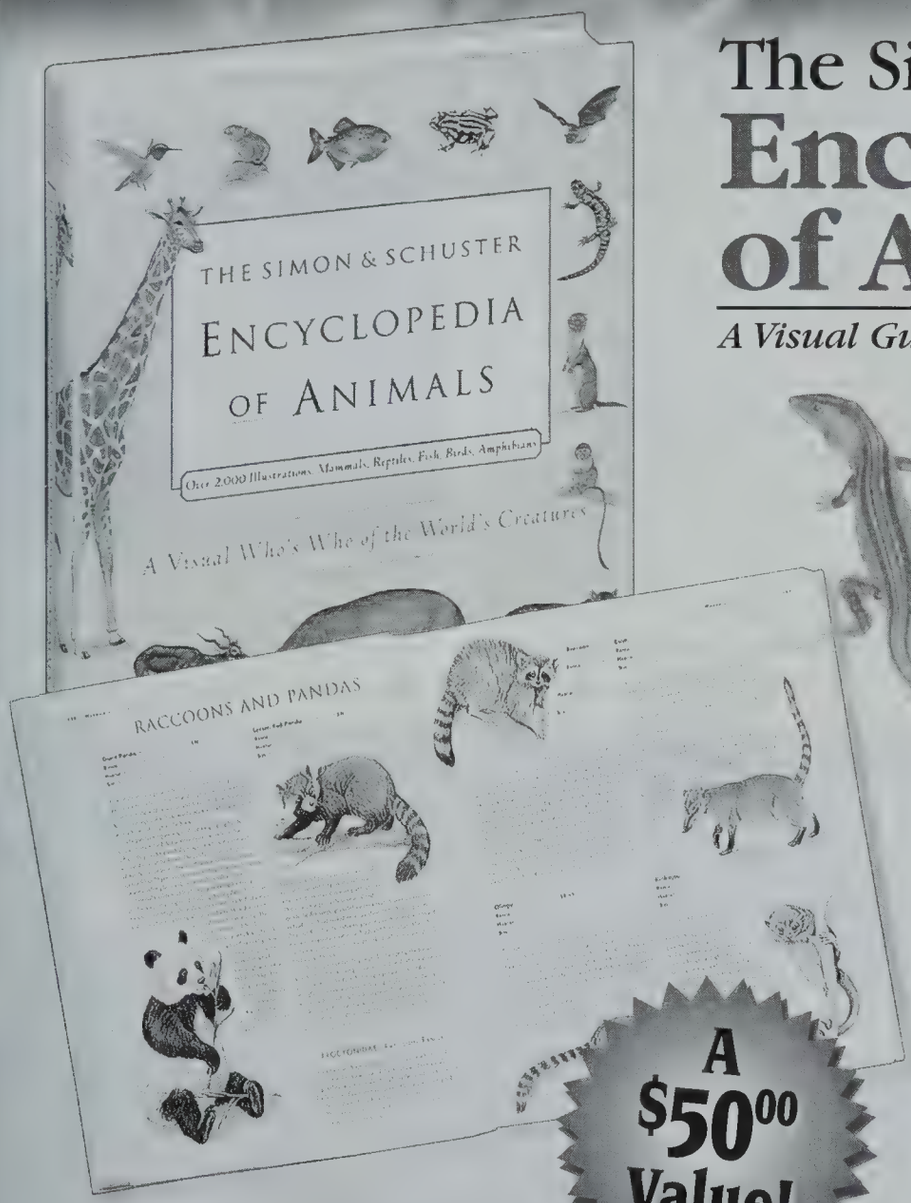
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THIS LAND

Cactus Country

An Arizona canyon provides a taste of desert and a glimpse of uplands.

By Robert H. Mohlenbrock ~ Photographs by Randy Prentice

Rising above the Sonoran Desert, the Santa Rita Mountains extend north to south, falling roughly midway between Tucson, Arizona, and Nogales, Mexico. The highest peaks, including 9,453-foot Mount Wrightson, are topped off with verdant forests of Engelmann spruce and ponderosa pine, while cacti and other desert plants grow at the base of the mountains, at about 3,000 feet, and penetrate dry canyons up to 4,000 feet. The range is a favorite among naturalists because of its varied plant and animal life and the scattering of natural springs, but only a few routes provide easy access into the rugged terrain. The most popular destination, reached by a highway that pierces the north side of the region, is a camping and recreational facility at the head of Madera Canyon; my favorite locale, however, is Agua Caliente Canyon, best reached from the west. Both canyons are under the jurisdiction of the Nogales Ranger District of the Coronado National Forest.

Lying at 3,600 to 4,200 feet, Agua Caliente Canyon harbors mostly desert

Jumping cholla

grassland and isolated stands of oak, while pinyon pine and alligator juniper are scattered on the surrounding dry, rocky slopes. Natural springs help feed some streams that flow intermittently

Purple prickly pear

in response to rainfall; other streambeds are washes, entirely dry except after heavy rains. One reason I am attracted to this canyon is that it is one of the few places in the United States where one can find two species of *Amoreuxia*, which are essentially tropical wildflowers. The birdlife, too, is alluring. Several species of hummingbirds flit about the blooms of the Arizona trumpet and the desert honeysuckle, while the rat-tat-tat of five different kinds of woodpeckers may be heard. Occasionally the elegant trogon, more common in Mexico, will fly overhead. Mammals are also plentiful. Although rarely seen, mountain lions and bobcats periodically cross the canyon. Likelier to be encountered are javelinas (collared peccaries) and coatimundis (large, ring-tailed cousins of the raccoon).

To get to Agua Caliente Canyon, exit Interstate 19 at Canoa Road and follow the east frontage road south before turning eastward into the canyon on Elephant Head Road. Eventually you will connect with a road that climbs along the south side of the canyon, heading toward the Smithsonian Institution's Fred Lawrence Whipple Observatory. Tours of that facility, located on the 8,585-foot summit of Mount Hopkins, depart from a visitors center and are available by reservation. Before you reach the visitors center, located at the base of Mount Hopkins, you will find a rough, unpaved road that leads off to the left for a quarter mile, down into the canyon, to Agua Caliente Spring. As its name indicates, the water from this spring is hot. Heated underground through geothermal processes, the water feeds an intermittent stream.

From the spring, you can pick up any of several hiking trails. One that heads toward Mount Hopkins passes two rocky knolls that top off at 4,962 feet and 6,012 feet. Together they are known as the Devils Cash Box, named for a 1909 gold strike. Intrepid hikers can also trek onward to the Madera Canyon campground or the summit of Mount Wrightson.

Robert H. Mohlenbrock, professor emeritus of plant biology at Southern Illinois University, Carbondale, explores the biological and geological highlights of U.S. national forests and other parklands.

For visitor information, contact:
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HABITATS

Desert grassland plants include many cacti, the most spectacular of which are the saguaro, with its thick, armlike branches, and a number of large chollas, such as the tree cholla, the jumping cholla, and the cane cholla. Also prominent are various prickly pears, with their flat, padlike stems, and the fiercely spined Arizona barrel cactus, which may grow to a

Arizona barrel cactus

foot in diameter and more than three feet tall. Smaller species include the Arizona rainbow cactus, sporting multicolored spines; claret cup, named for its flower; pancake cactus, which grows up to four inches in

Ocotillo

diameter and lies flat on the ground; pincushion cactus, which stands about two inches tall; and the two- to five-inch-tall nipple cactus, whose stems end in small rounded tips.

A plant with cactuslike spines that is actually related to Mexico's boojum tree is ocotillo. After a rain, its barren, gray-black stems change overnight to green as small leaves emerge from buds covering the plant. After a few days of dry weather, the leaves fall off and the plant resumes its dormant appearance. While cactus flowers have many petals, the ocotillo's red flowers have only five, united at their base to form a tube.

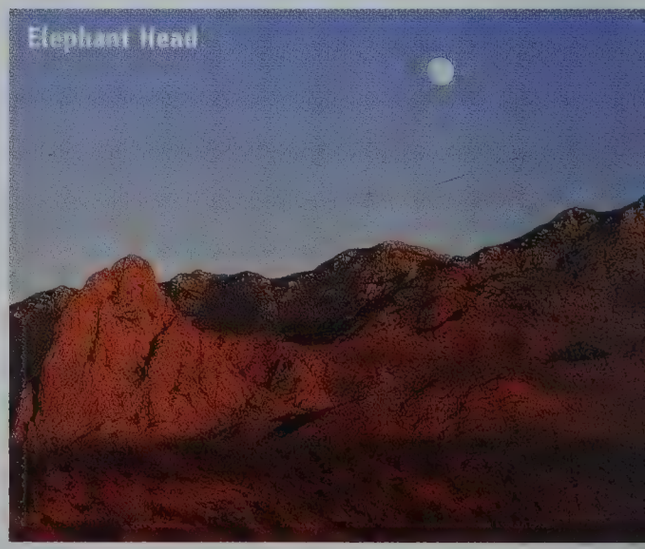
Stands of oak may appear in shallow depressions and other places that have slightly more moisture. The dominant (and often only) species is Gambel's oak.

Dry, rocky slopes support a few kinds of stunted trees, among them Gambel's oak, silverleaf oak, pinyon pine, and alligator juniper. Most do not grow more than twenty feet tall under the arid conditions. Typical shrubs include squawbush (a type of sumac); coral bean and fairy duster (both members of the pea family); two types of hibiscus, or rose mallow; and cliff Fendler bush. Snapdragon vine, a plant with arrowhead-shaped leaves and dark red or bluish purple flowers with a yellow center, scrambles over some of the shrubs. Prickly pear cacti found here are the clock-face prickly pear, Engelmann's prickly pear, cliff prickly pear, and purple prickly pear. Wildflowers that grow scattered in rocky soil include pine-needle milkweed, Arizona trumpet, long-leaved phlox, and a true wild cotton. Two uncommon species with three-inch-wide orange flowers are *Amoreuxia palmatifida* (yellow show) and *A. gonzalezii,* the only two members of the tropical Cochlospermaceae family that are found in the United States.

On some dry slopes—perhaps because they are not quite so rocky—shrubby species include quinine bush, silk tassel bush, desert sumac, mescat acacia (white thorn), and wait-a-minute bush (a type of mimosa). Wildflowers that grow here are dogweed, springleaf zinnia, wedgeleaf scurfpea, and trailing windmills (a creeping plant whose flowers are grouped by threes into what appear to be single blossoms).

Streams, although they may flow only intermittently, help support the growth of several trees, among them blue palo verde, mesquite, velvet ash, small-leaved mulberry, netleaf hackberry, and soapberry. A common shrub is seep willow, a member of the aster family whose narrow leaves resemble those of willows. Wildflowers near streams include the bright-yellow-flowered monkey flower; a *Mecardonia* with tiny purple snapdragon-like blossoms; a thoroughwort with lavender flower heads; and Albert's dome, a plant with yellow flower heads that each have a central raised dome.

Washes support only plants that can survive long stretches of extremely arid conditions. Two shrubs here are desert broom and burro bush, while wildflowers include desert honeysuckle, with long, tubular, brick-red flowers, and woolly feverfew, with white or greenish flowers.


Elephant Head

The glacier-carved freshwater fjord at Western Brook Pond.

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CELESTIAL EVENTS

"Ptolemaic System," from *Harmonia Macrocosmica* by Andrea Cellarius, 1661

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Center Stage

Repositioning the Sun at the hub of our celestial neighborhood was only the first step.

By Richard Panek

It almost goes without saying that today we wouldn't think of the solar system as "solar" if there had been no Copernicus to put the Sun at its center. But more than 450 years after the beginning of the Copernican revolution, it can be difficult to remember that "solar" is only half the story.

When we look at the night sky now, we take for granted that the little lights that wander—the planets—bear a greater resemblance to Earth than they do to all the little lights that don't wander—the fixed stars. For thousands of years, however, the reverse seemed true. Earth was Earth, and the little lights were little lights, whether they were on the move or not. The conceptual divide was between Earth and just about everywhere else—between "here" and "there." If a further distinction existed out "there," dividing planets from stars, it fell, vaguely, between "far" and "farther."

The Copernican system alone didn't necessarily change that. To be sure, it rearranged the heavens, dispatching the Sun to the center of the universe and sending Earth, the planets, and the stars spinning in orbit around it. But for an earthly observer, the basic distinction between here and there continued to hold.

Only with the advent of the telescope in the early seventeenth century did astronomers begin to identify similarities between Earth and the other planets, such as their shared global shape and the presence of moons. And only with the invention of dedicated precision instruments throughout the rest of the century did astronomers begin to appreciate the relative distances to celestial objects. As Rice University historian of science Albert Van Helden once wrote of this era's technology, "Every new discovery brought the planets closer to the earth, and every improvement of the telescope showed the stars to be even farther away."

Early in the seventeenth century—at the end of the reign of the geocentric universe—most astronomers estimated the distance to the fixed stars to be 20,000 Earth radii. By the turn of the eighteenth century, that estimate stood at 20,000,000,000 Earth radii—a millionfold increase. On such a scale, the planets suddenly didn't seem so far after all. However improbably, those wandering lights in the night sky were relatively near, leaving the stars alone to occupy the impossibly vast stretches of far and farther.

Nothing captured this new celestial hierarchy better than the coining of the term "solar system," which apparently dates from the early 1700s. In the three centuries since then, our ears, sensitized by the Copernican revolution, have come to hear an emphasis on the word "solar." But the understanding that Earth belongs to a system was no less profound.

By the end of the eighteenth century, philosopher Immanuel Kant and mathematician Pierre-Simon de Laplace had independently proposed that the Sun and planets shared a common birth, condensing out of a mass of gas. Despite some untenable details of their hypothesis, the German astrophysicist Carl Friedrich von Weizsäcker retained much of their basic thinking in the more sophisticated model of the nebular

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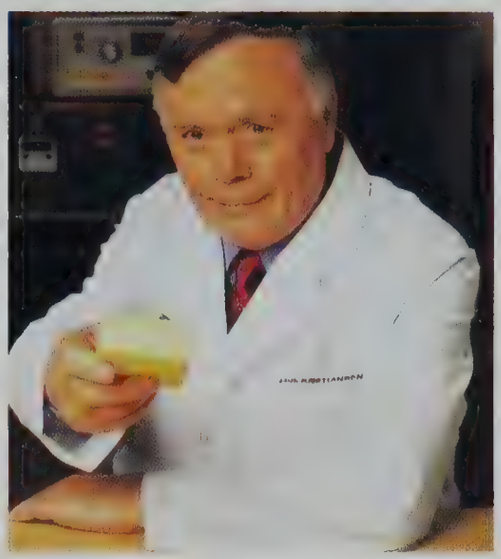

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evolutionary process that he worked out in the 1940s.

Indeed, our conception of the solar system continues to evolve to this day. Just within the past decade, astronomers have discovered Kuiper Belt objects—small, icy bodies at the outer reaches of the solar system that may number in the billions. As University of Arizona researcher Jeffrey Larsen reported at an astronomy meeting this past August, "Our solar system seems to be populated with many objects that even a few years ago were not seen because they are extremely faint. We still do not know yet how far out they go."

Or do we? In late October, just two months after Larsen spoke, three researchers announced that although they had conducted six extensive surveys, they hadn't detected any Kuiper Belt objects at a distance of more than fifty-five astronomical units (AU) from the Sun, approximately at the outer range of Pluto's orbit. (One AU equals the distance between Earth and the Sun, or about 93 million miles.) Does the solar system really peter out at Pluto? Or will better technology and instrumentation reveal fainter objects? And how would either scenario alter current theories of solar system formation?

While astronomers ponder these questions, the rest of us can enjoy an especially spectacular planetary display in February by our solar system

THE SKY IN FEBRUARY

Mercury reaches inferior conjunction on February 13. The planet comes back into view during the last week of the month, appearing low in the east-southeast before dawn.

Venus hangs in the western sky this month as darkness falls. Climbing as high as 42° above the horizon at sundown in midnorthern latitudes, it sets about three and a half hours after the Sun. It is so bright during February that observers should have little trouble finding it, even before sunset. The 20th is the date of its greatest brilliancy. Viewed through a telescope, the planet's crescent appears to grow both larger, as it approaches Earth, and thinner, as it shows us more of its night side. By month's end, Venus's disk is large enough for viewers to recognize its crescent phase (using binoculars with at least 7x magnification).

Mars can be found in the constellation Libra at the beginning of February but crosses over into Scorpius on the 19th, remaining there for the rest of the month. Throughout February it appears to rise out of the southeast between 1:00 and 1:30 A.M. Local Standard Time (LST). As the planet draws nearer to Earth—its distance shrinking from 137 million to 112 million miles—it brightens by half a magnitude, reaching +0.5 by month's end. Mars appears to pass less than 2° below the Moon on the morning of the 15th.

Jupiter, at magnitude -2.4, ranks next to Venus in brightness this month. The giant planet is visible all evening; look for it near the meridian at sunset as it disappears below the western horizon at about 2:00 A.M. LST at the beginning of February and about midnight by month's end. The ruddy first-magnitude star Aldebaran can be found southeast of the planet. Jupiter seems more than twice as bright as the star Sirius, which at early evening sparkles in the southeastern sky, below and to the left of the bright planet. On the evening of the 2nd, when the Moon is just past first-quarter phase, it slips below Jupiter.

neighbors. On the first day of the month, Jupiter and Saturn will line up strikingly with the first-quarter Moon in the southern sky. And on February 20 and 21, Venus will reach a magnificent -5.4 magnitude, the brightest it will be until the end of 2002. Without magnification the planets can never be anything more to earthly observers than lights that wander. Even so, they can also serve as nightly reminders of how much our understanding of the universe has changed, near and far.

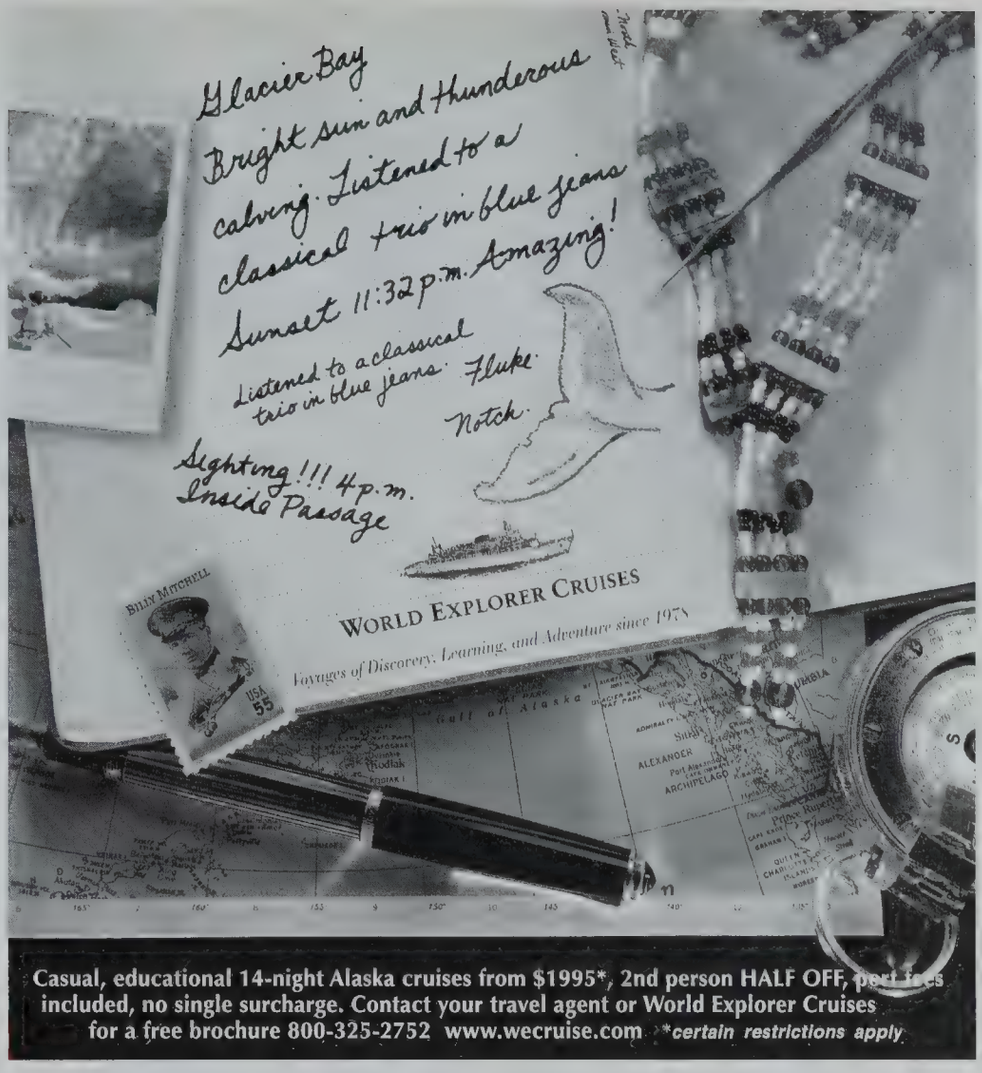
Richard Panek is the author of Seeing and Believing: How the Telescope Opened Our Eyes and Minds to the Heavens *(Penguin, 1999).*

By Joe Rao

Saturn, found near the meridian this month during evening twilight, sets after midnight LST. It appears as a yellowish white, zero-magnitude "star" in the constellation Taurus, about 8° southwest of the Pleiades and about the same distance west of the much brighter Jupiter. Tipped at about 24.5° to our line of sight, Saturn's famous ring system can be easily viewed, through even a small telescope. At dusk on February 1 and again on the 28th, the Moon, Saturn, and Jupiter will appear stretched out in a line.

The Moon is at first quarter on February 1 at 9:02 A.M.; full Moon is on February 8 at 2:11 A.M. Since the full Moon occurs only nine hours after reaching perigee (its nearest point to Earth), ocean tides will be much higher than normal for a few days around this date. Last-quarter Moon is on February 14 at 10:23 P.M., and the new Moon falls on February 23 at 3:21 A.M.

Unless otherwise noted, all times are given in Eastern Standard Time.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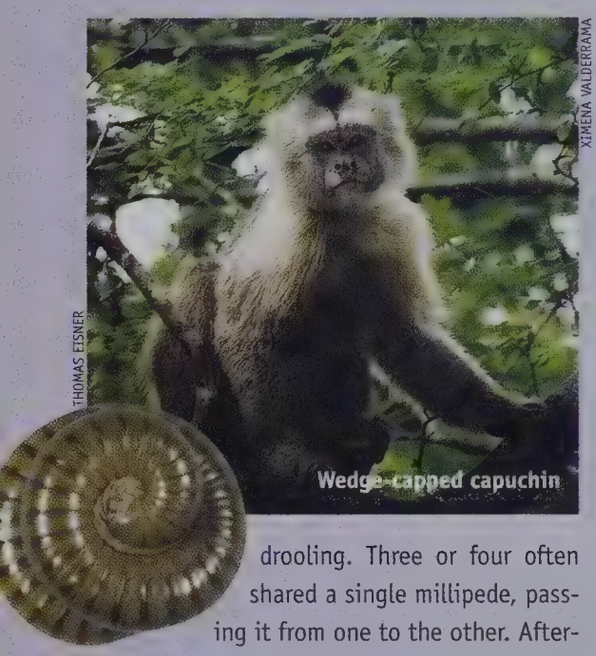
MONKEYING WITH MILLIPEDES

Twenty years ago, ecologist John Robinson, of the Wildlife Conservation Society, observed puzzling behavior in a group of wedge-capped capuchin monkeys *(Cebus olivaceus)* in central Venezuela. Upon finding a millipede, the monkeys rubbed it all over their bodies, their eyes appeared to glaze over, and they frequently placed the arthropod in their mouth while



drooling. Three or four often shared a single millipede, passing it from one to the other. Afterward the monkeys rubbed up against one another, apparently to spread the millipede's secretions. Up to ten bouts of this frenetic, ecstatic anointing could take place within a single day.

In 1988 Robinson invited his student Ximena Valderrama, now in Columbia University's anthropology department, to conduct a two-year follow-up study at his field site. Valderrama collected some of the millipedes *(Orthoporus dorsovittatus)* used by the monkeys and sent them to chemical ecologists Thomas Eisner and Athula Attygalle, of Cornell University. After "milking" the millipedes for their secretions, which are produced by glands along their sides, the chemists determined that they contained benzoquinones, which are powerful insecticides and disinfectants.

Because the monkeys anoint themselves exclusively during the rainy season, when they are vulnerable to infection by mosquito-borne botfly larvae, Valderrama and her colleagues hypothesize that the animals intentionally apply the benzoquinones as protection against biting insects and parasites. Although millipede secretions contain other toxins and even carcinogens, they appear to cause the monkeys no harm. ("Seasonal Anointment With Millipedes in a Wild Primate: A Chemical Defense Against Insects?" *Journal of Chemical Ecology* 26:12, 2000)

A VEGETARIAN CROCODILE

Until now, the fossil record of the last 200 years has presented a remarkably stable array of crocodiles. Several gigantic varieties appeared during the age of the dinosaurs, but these long-snouted, aquatic carnivores seem not to have undergone any radical changes over the eons. Recently, however, paleontologist Gregory Buckley, of Roosevelt University in Chicago, and his colleagues unearthed the fossil skull of a previously unknown crocodile—and it appears to have been a short-snouted vegetarian.

Simosuchus clarki, extracted from approximately 70-million-year-old rocks in Madagascar, has a short pug nose, a tall head, and nostrils that point out from the front of the face, not upward, as in typical living crocodilians. Some features of the thick skull suggest that it may have been an adept head-burrower. An adult *Simosuchus* would have been only about three feet long.

The most unusual feature of the new species is its multicusped teeth, which resemble those of presumed herbivorous dinosaurs such as ankylosaurs and stegosaurs. *Simosuchus* seems to have undergone a convergent evolution with

these armored, tanklike dinosaurs. In addition to the similarities in tooth form, this species had a broad, compact body and a heavy-boned skull like those of the dinosaurs. However, its skull also shows the characteristic osteoderms, or bony plates in the skin, that distinguish crocodiles from their dinosaur relatives.

The new fossil also presents a puzzle for geologists because of its resemblance to *Uruguaysuchus,* an extinct crocodile from South America. Buckley and his colleagues think this suggests that Madagascar and South America may have been linked 80 million years ago, long after the young Atlantic Ocean is believed to have separated the two landmasses. ("A Pug-Nosed Crocodyliform From the Late Cretaceous of Madagascar," *Nature* 405, 2000)

IDENTICAL EMU TWINS

A group of researchers in New Zealand has documented the first case of identical twinning in birds. S. M.

Bassett, of the Ratite Research Centre at Massey University in New Zealand, and several colleagues describe two emu chicks *(Dromaius novaehollandiae)* hatched from the same extraordinarily large egg at an emu farm in Colyton, New Zealand. The egg was artificially incubated, and humans assisted the two female chicks to emerge from the shell. Although their combined weight on hatching was about the same as that of a single normal chick, by eighteen months of age they were near average size.

Fraternal twinning—two fertilized ova becoming trapped inside a single shell—is a rare but well-documented occurrence in some birds. As with human fraternals, the two birds are no more closely related than are ordinary siblings. A DNA analysis of the New Zealand emu hatchlings' blood showed a complete genetic match, however, indicating their formation from a single ovum that split after fertilization. ("Genetically Identical Avian Twins," *Journal of Zoology* 247, 1999)—*Richard Milner*

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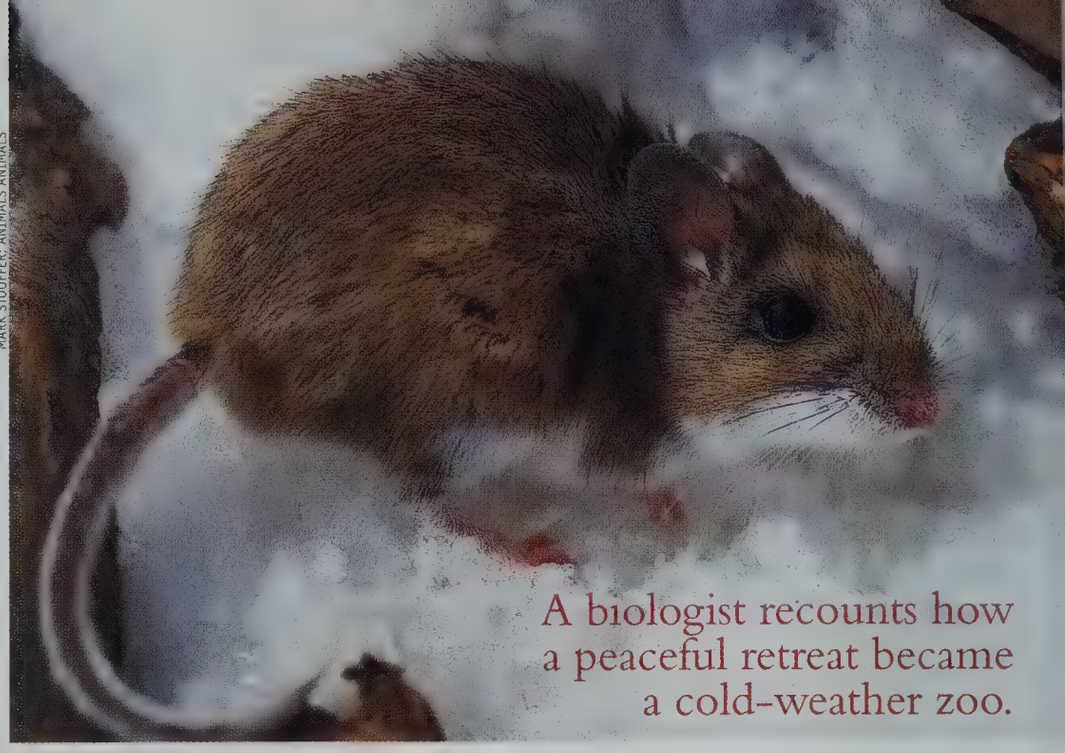

MARK STOUFFER: ANIMALS ANIMALS

A biologist recounts how a peaceful retreat became a cold-weather zoo.

Winter Guests

By Bernd Heinrich

Even before I finished building the cabin, I could see that it had potential. Bubo, my tame great horned owl, perched on one of the rafters rather than staying out in the woods, where the blue jays harassed it. Similarly, as soon as I crossed the doorstep, the June hordes of bloodsucking blackflies and horseflies left off their hot pursuit. Aside from harboring a few stray houseflies in late summer, the inside of the cabin was a sanctuary. When winter came to the Maine woods, however, my cabin became more appealing to the wild local fauna, and many adopted my haven as their own. As a first-time log cabin builder, I had made many construction mistakes, and the biggest was not anticipating the entrance of winter guests—thousands of them.

Among mammals, my annual visitors now include a few common smoky shrews, short-tailed shrews, red-backed voles, and, last but certainly not least in numbers, deer mice. As far as I'm concerned, all are welcome except the cutest of the lot, the deer mice. Normally, deer mice spend winter high in tree holes, where they build cozy nests and stay warm by huddling in groups. Since I built the cabin, I've done my best to plug every conceivable opening with oakum, a sisal fiber more often used to stop holes in wooden boats, but deer mice seem to penetrate the cabin more easily than water does a boat. The mice apparently get inside through tiny apertures and then create more openings by pulling out the oakum plugs between the logs. In this they are aided by the larger and stronger flying squirrels that use the oakum for lining their winter nests in natural tree holes or in birdhouses that I provide, primarily for other occupants.

On any winter night I can hear swarms of deer mice scampering overhead in the space between the metal roofing and a sheet of insulating Styrofoam. At intervals the footsteps stop and I hear crunching as the mice chew the Styrofoam as well as the tar paper beneath it. White Styrofoam flakes stream down like snow all over the bed and floor. Once inside, the mice shred clothing for their nests, leave peanuts in my bed, and burrow into the dry goods. The possibility that they might carry disease tweaks at the back of my mind, too. If I set traps, I commonly catch up to four mice in a night, but many more have the run of the place. The joint efforts of the deer mice and the flying squirrels also appear to provide the main means of entrance for "the crowd."

The crowd is always snug inside, come winter. It consists mostly of cluster flies. According to Harold Oldroyd, who wrote the fly bible, the 1964 *Natural History of Flies,* there are several species of these robust flies of the genus *Pollenia.* Most of them are several times the size of houseflies. *Pollenia* are calliphorid, or "flesh," flies. The larvae of our native species eat the flesh of dead animals, but the species in the cabin, *Pollenia rudis,* was introduced from Europe, and the larvae parasitize earthworms. Big and bristly, these flies are not handsome, in contrast to the metallic green or gun-barrel blue of our native *Pollenia* (which never enter the cabin at all).

In the fall *P. rudis* perch in crowds on the logs outside the cabin and sun themselves. When it starts to get cool, they slip through the cabin cracks. By November most of them seem to have made their way inside, but they remain totally unobtrusive unless I build a roaring fire in the woodstove. Then, within minutes, they come poking out of all the crevices and, in an hour or so, if it is still daylight, gather by the thousands in buzzing masses at each of the eight windows, making a collective hiss. They apparently perceive the warmth as the return of spring and take it as their signal to try to leave by flying directly to the light at the windows. If offered an exit, at least they do not try to stay

on. Even on the coldest days, if I open the windows, they rush out and fly a short distance before the cold grips them and they fall to the snow. The flies are not dead, only immobilized. When subjected to the cold of a Maine winter, these flies quickly become cold-hardy, being physiologically equipped to endure low temperatures. Under lab conditions, I have found that some succumb to freezing at -20° C if cooled rapidly, while others can rebound from -10° C and crawl about within seconds of being warmed up, like those in the cabin.

The larvae of numerous species of ants and beetles spend the winter inside tree trunks, where they endure temperatures close to that of the ambient air. Unlike the quickly revived flies, the larvae I have brought into the cabin seem stone dead even after hours of relative warmth. Only after a few days do they begin to show signs of life. The substances that fortify these larvae against the cold may also account for their lengthy stupor. Ant and beetle grubs contain glycerol or other sweet-tasting "antifreeze" (I have not tasted the flies), which prevents ice-crystal formation in the body, renders them inactive, and also takes a long time to leave the blood.

The other winter cabin guests—primarily of three species—are beautiful and more benign in habit. When the cabin is heated, for example, they don't have the annoying *P. rudis* tendency to hover around the bed light and then, when it's turned off, to dash under the covers and buzz there rudely.

The first of these, mourning cloak butterflies, usually remain in crevices outside and only rarely make it into the cabin. In the fall I commonly see one or two fluttering under the roof. The second species has arrived here in numbers only in the past few years. These occupy the cabin by the thousands some years and by the dozens in others; this winter, none have appeared. They are multicolored Asian ladybugs or ladybird beetles, first introduced to the southern United States to control aphids. Like many of our endemic species of ladybirds, these beetles have handsome red-and-black coloration. Asian ladybugs, however, are more varied. Their "background" hue can be deep red or orange or yellow. They may have no spots or have tiny black dots or spots that coalesce into black bands.

Not everyone has fond feelings for these beetles. In some parts of the country, they themselves have become pests by their sheer numbers as they adapt to life in vertical dwellings rather than their traditional Asian crevices and caves. And like many other insects whose bright colors serve as a warning to stay clear, multicolored Asian ladybugs taste bad to predators and give off a noxious smell when crushed. My tolerance for the beetles stems from their own predatory habits. Multicolored ladybugs and their larvae feed on aphids and other plant-sucking insects, such as the woolly adelgid, which is decimating hemlock stands from Virginia to New England. It is claimed that as it develops, a single multicolored Asian ladybug can devour 600 to 1,200 aphids. The adelgid was introduced from Asia and became a serious problem in the mid-1980s, close to the time the Asian ladybird beetles first started showing up in my cabin. Once attacked by adelgids, a hemlock tree dies. So far, I have not had a problem with adelgids on my hemlocks, and I welcome the beetles into their overwintering home.

JAMES H. CARMICHAEL; PHOTO RESEARCHERS, INC.

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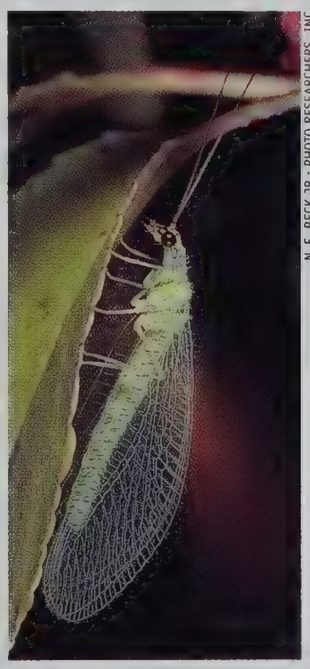

N. E. BECK JR.; PHOTO RESEARCHERS, INC.

Opposite: Deer mouse, wanted for breaking and entering. Above: Welcome visitors include the mourning cloak butterfly (top left), multicolored Asian ladybug (bottom left), and green lacewing.

The third insect that is a regular but never abundant visitor is the green lacewing. The light, bright green of this insect extends to its four wings, delicate membranes stretched between a network of veins. To me, lacewings have a certain aura. But this is lost on aphids. Lacewing adults as well as their larvae, commonly called aphidlions, are ferocious predators. In the woods I often find the adults hibernating under loose dead bark in the winter. They are rare enough in the cabin to be a treat.

The diversity and abundance of winter wildlife is not unique to my cabin. Anyone can be similarly blessed. By allowing a few openings, I now play host to the good, the bad, and the beautiful.

Bernd Heinrich is a professor of biology at the University of Vermont, Burlington.

Nightlife of Social Caterpillars

For cold-adapted larvae on the peaks of the Sierra Madre, the action begins after dark.

By Terrence D. Fitzgerald

Illustrations by Utako Kikutani

ROBERT AND LINDA MITCHELL

Above: Madrone trees festooned with caterpillar nests. Scenes of a life cycle, opposite, clockwise from upper right: Tiny yellow-green hatchlings; mature caterpillars tending the nest; pupation; mating; and egg laying.

I began to suspect there might be trouble ahead when we had driven for many miles without seeing any cars in the oncoming lane. We had gotten a late start and were traveling at night along twisting and precipitous Highway 41, which leads from the Mexican coastal town of Mazatlán east to the city of Durango, some 180 miles from the Pacific in the Sierra Madre Occidental range. My colleague Dessie Underwood and I had come to this rugged region to study the madrone caterpillar, the larval stage of the pierid butterfly *Eucheira socialis,* a distant relative of the cabbage white butterfly familiar to North American gardeners. Living in colonies at elevations of approximately 8,000 feet, madrone caterpillars nest on the branches and feed on the leaves of the madrone tree, which grows on the fringes of pine forests on the mountain peaks and keeps its leaves all winter. Although snow is rare here, nights are cold and frost is common. But throughout the winter, the madrone caterpillars continue to feed and grow, foraging under frigid conditions that few other insects could tolerate. Dessie and I had teamed up to study their ability to survive deep winter in the mountains.

As our car approached a tortuous part of the highway aptly called Espinazo del Diablo, or "spine of the devil," we encountered a massive gridlock of vehicles stranded by black ice. Motorists huddled around makeshift fires dotting the sides of the highway. It wasn't until late the following morning, after the sun had melted the ice and a pathway was opened through the maze of stalled vehicles, that we were able to continue on our way. Arriving at our study site later that day, we realized we weren't the only victims of the cold. Some madrone trees and their caterpillar colonies had escaped damage, but throughout the forest we saw pockets of frost-damaged madrone trees with colonies of dead, frozen caterpillars hanging from the branches. Records we obtained from a local weather station indicated that the colonies had probably been killed shortly before our arrival, when temperatures fell to as low as 9°F night after night for more than two weeks. Madrone caterpillars push the physiological limits of insects in dealing with cold temperatures, and although they can resist freezing during most winters, they are clearly susceptible to prolonged spells of severe cold.

The madrone caterpillar is one of some 300 species of caterpillars that live in social groups. (More than 140,000 Lepidoptera species exist worldwide.) According to Peter Kevan and Robert Bye, who studied the insect's general life history in the early 1990s, the Aztecs called it *xiquipilchiuhpapálotl,* or "butterfly that makes a pouch." The brilliant white, baglike nests that house the colonies are typically six to eight inches in diameter and are constructed of pure silk. Native peoples used these tightly woven shelters to make containers and fabric. The conspicuous nests, which can number twenty or thirty per tree,

also attracted the attention of the explorer Alexander von Humboldt during his travels in Mexico in the early 1800s. Von Humboldt observed the caterpillars and used the nest material as parchment, signing his name in 1804 on a section cut from a nest.

While the bag nests are feats of caterpillar architecture, the insects' enduring family bonds and the recently discovered fact that the colonies are composed largely of males are what make the madrone caterpillar unique, so far, among social caterpillars. Each colony consists of up to several hundred siblings that remain together for nearly a year, pupating as a group and then transforming into butterflies while still sequestered in the nest. The female butterfly lays her cluster of eggs on a madrone leaf during the rainy season, in June or July. The young caterpillars hatch from these eggs in about three weeks and remain together to forage and to spin silk; eventually they cover a few leaves in a veil of silk, creating a primary nest within which they will rest between bouts of feeding. As fall approaches, the caterpillars quicken the pace of their spinning and create a secondary nest that completely engulfs the primary one. The walls of this outer nest are highly fortified, consisting of tens of thousands of strands of silk so tightly woven that the nest will hold water and a sharp instrument is needed to penetrate its walls. The caterpillars will spend the rest of their larval lives—some eight months—in the expanded nest, leaving it only to feed. (Some other lepidopterans have a lengthy larval stage, but most spend far less time as caterpillars than the madrones do. In the tent caterpillars of eastern North America, for example, the larval stage lasts eight weeks.) To feed, madrone caterpillars enter and exit the nest through a small opening at the bottom. Otherwise the nest is an impenetrable fortress, excluding birds, wasps, and most other predators that might find the caterpillars a tasty meal.

Eucheira socialis, the butterfly that develops from the madrone caterpillar, lays her eggs on a madrone leaf. Females usually mate and deposit their eggs on the same day they leave the nest as adults. Mission accomplished, they soon perish.

TERRENCE D. FITZGERALD

Although the primary function of the nest may be to protect its inhabitants from their natural enemies, our studies show that the structure is also essential for caterpillar growth during the winter. At our study site, evening temperatures begin to fall below freezing in October and continue to do so until the following May. From December to February, nighttime lows average 18°F. The days are relatively warm, but the temperature plummets when the sun sets. By the time darkness envelops the forest, the temperature on a typical night will have already fallen to 41°F or less—chilly enough to bring the activity of most insects to a standstill. Yet this is just when the colonies of the madrone caterpillar stir to life.

Our nocturnal fieldwork revealed that the caterpillars leave the nest each evening at dusk. After adding silk to the nest's outer walls, they travel up to ten feet away on the tree and feed until early morning. Usually they return to the nest before dawn, their guts packed with leaves. If the overnight temperature falls below a certain level—known as an insect's chill-coma temperature—all activity ceases, and the inert caterpillars are able to return to the nest only after basking in the rays of the early morning sun. Chill-coma temperatures vary among insects; that of the madrone caterpillar is 28°F. Only one other caterpillar—a subarctic species—is known to have a chill-coma temperature this low. Even when overnight temperatures remain above freezing, however, the physiology of the caterpillars is taxed: at 77°F, madrone caterpillars travel three feet in less than three minutes, but at 41°F, they take half an hour to cover the same distance. So why do these caterpillars press their limits at night, when they could bask in the sun and feed efficiently and at leisure during the day? One explanation is that nocturnal foraging may have evolved in this species in response to predators that are active during the day.

Each colony consists of up to several hundred siblings that remain together for nearly a year.

Although they feed by night, madrone caterpillars cannot digest their food until morning, because they need heat to process what they take in. Like miniature greenhouses, the nests trap the radiant heat of the morning sun, and the caterpillars within the nest are able to warm their bodies rapidly to the relatively high temperature needed to drive the processes of digestion and growth. The temperature of the interior of one nest that we measured in January rose from 25°F to 75°F in just one hour, exceeding the outside air temperature by 30°.

Studies that Dessie Underwood conducted with Arthur Shapiro at about the same time as we were doing our thermal ecology research showed that in colonies of madrone caterpillars, brothers outnumber their sisters by as many as four to one

and that, even for their numbers, these males do a disproportionate amount of work involving nest construction and maintenance. Such strongly biased sex ratios are rarely encountered in insects; when they are, as in ants and bees, females predominate. Underwood and Shapiro observed madrone caterpillars over six generations. The persistence of the uneven sex ratio over these generations suggested that producing more males than females is advantageous to the colony as a whole. With their numerous brothers doing most of the work, sisters can save energy and use the nutrients they take in to fuel the maturation of their ovaries. The leaves of the madrone tree contain little nitrogen, which is necessary to build proteins, and the colony will benefit if the females channel this nutrient into the production of eggs—that is, the next generation of madrone caterpillars—rather than silk. At maturity, the female caterpillars weigh up to twice as much as their hardworking brothers.

CHRISTIAN HEEB; GNASS PHOTO IMAGES

Madrone caterpillars live at elevations of about 8,000 feet in Mexico's Sierra Madre Occidental range. Below: In autumn, some of the caterpillars, typically males, blaze a silk trail along tree branches leading from the nest to patches of leaves they will harvest in winter.

TERRENCE D. FITZGERALD

In addition to constructing an efficient heat-trapping nest, the caterpillars prepare for winter by laying down an extensive network of silken trails from the nest to food sources. Because they slow down in the cold, the caterpillars would be unable to travel very far from the nest if they had to blaze new trails in the dead of winter. They solve this problem by establishing the trails before cold weather sets in. By late fall, prominent silk pathways issue in all directions from the nest, each leading to a patch of leaves the caterpillars will harvest during the winter. The energetic males are usually the first to venture forth in autumn, and they secrete most of the silk that marks the pathways along the tree's branches.

Silk helps the caterpillars move more rapidly and obtain purchase on the madrone's smooth limbs, from which they might otherwise slip during their cold-induced nighttime lethargy. To find their way along these paths, however, the caterpillars depend not on the silk but on a pheromone. Each evening, the first caterpillars to head out (again, usually males) lay down fresh stimulant by intermittently brushing against the silk path with the tips of their abdomens and secreting the pheromone. Once established, the chemical trail is followed and reinforced by their colony mates. Critical to foraging success, it not only enables the larvae to stay together during their trips away from the nest but, like pebbles dropped on the forest floor by a traveler, also allows them to find their way back home. Studies show that the caterpillars can detect the pheromone at concentrations of far less than a billionth of a gram per millimeter of trail.

By the time warm weather returns in the spring and the caterpillars prepare to pupate, they will have gathered enough food and stored sufficient energy during their nightly forays to sustain them for the brief remainder of their lives. At this point the colonies of most species of social caterpillars disband, and individual larvae seek secluded pupation sites, but madrone caterpillars retain their social bonds and pupate en masse inside the nest. Prior to metamorphosis, the caterpillars pack together and suspend themselves by the tips of their abdomens from the inner walls. (At this stage the insects are plump and nutritious; indigenous peoples collect mature nests, extract the pupae, and then roast and consume this conveniently packaged food source.) The reproductive success of a colony—its success at passing on its genes to a new generation—can be largely gauged by the weight

of its female pupae. When Underwood and Shapiro created experimental colonies with different ratios of male to female caterpillars, they found that male-biased colonies produced the largest pupae.

Having performed their critical role in the success of the colony, many males perish before they have a chance to pupate. On spring days, numerous caterpillars can be found lying listlessly on the outer surface of their nests, where they wither and die. Underwood and Shapiro found that almost all these individuals are males, with no indications of disease, predation, parasitism, or any other clear cause of death. Their studies have shown that males spend less time feeding than their sisters do and occasionally spend the whole night spinning and moving about the nest without venturing out

By late fall, prominent silk pathways issue in all directions from the nest.

to feed. Perhaps the ones that die prematurely are undernourished and simply lack the physiological resources necessary to fuel the metamorphoses that would convert them into pupae and adults.

After several weeks of transformation within the nest, the butterflies emerge from their pupal cases. Now, in the final and most fleeting phase of their lives, the insects abandon their habit of moving about only under the cover of darkness. One by one, the mature males and egg-laden females work their way through the nest's opening to the sun-filled world outside. Not all manage to escape. Some die in the attempt to break free of an unyielding pupal case, and occasionally we find a nest choked with dead butterflies at an obstructed opening.

Despite the death of many males in the caterpillar stage, they still outnumber females as adults and are likely to encounter stiff competition as they fly about the madrone trees in search of mates. After surviving a long winter as caterpillars, the *E. socialis* butterflies have only a few days in the sun. The females commonly mate and deposit their complement of eggs on the same day they escape from their nest, and, being spent, they die shortly thereafter. The males, too, live just several days. Still, they will have completed their mission. In only a few weeks' time, madrone caterpillar young, adapted to the rigors of winter nights in the Sierra Madre, will replace them in a new cycle of life. □

The communal nest, below, serves as both a fortress and a solar-heated retreat. Opposite: Snug within the shelter by day, the caterpillars leave to forage at nightfall, following pheromone-laced silk paths.

ROBERT AND LINDA MITCHELL

Story by John Malcolm Russell ~ Photographs by Alexandra Avakian

Robbing the Archaeological Cradle

In the aftermath of the Gulf War, Iraq's ancient heritage has landed on the endangered list.

Virtually all of Iraq is an archaeological site, so the 1990–91 Gulf War inevitably took a toll on the remains of ancient settlements, some well known and others still awaiting discovery and exploration. One of these sites was Ur of the Chaldees, the reputed birthplace of Abraham, where excavations in the 1920s and 1930s had yielded a great temple complex as well as royal tombs packed with sacrificed servants and gold treasures rivaling the riches of Tutankhamen. Bombing and strafing left four large craters in the temple precinct and some 400 holes in the temple's great ziggurat, or stepped tower. Far worse, following the cease-fire and the imposition of sanctions, the weakened Iraqi authorities were powerless to protect most of the country's museums and archaeological sites from looting and theft. Even now, a decade later, the nation's Department of Antiquities and Heritage is short of needed resources. As a result, thousands of artifacts have been smuggled out of Iraq and offered on the international market. Furthermore, in the course of an emergency agricultural development program aimed at averting food shortages, the Iraqis have bulldozed, plowed, inundated, and irrigated countless ancient sites. What is being lost is not only Iraq's heritage but the world's.

A guard stands at the entrance to Hatra, an Iraqi site that has been subject to looting. Hatra's buildings belong to the period when the Iranian empire of Parthia enveloped much of Iraq.

Called Mesopotamia by the Greeks and variously Sumer, Akkad, Babylonia, and Assyria by its own ancient inhabitants, Iraq has an excellent claim to be the cradle of Western civilization. The emergence of complex communities was accompanied by developments such as writing, the wheel, irrigation agriculture, cities, monumental architecture, state-sponsored warfare, organized religion, written laws, kingship, a wealthy class, imperialism, centrally organized production of hand-crafted goods, and large-scale trade. By and large, the first eleven chapters of Genesis are set in southern Iraq, in the land of Shinar (Babylonia). *Eden,* the Sumerian word meaning "steppe," was the name of a district in Sumer, or southern Babylonia. Mesopotamian royal gardens, notably the Hanging Gardens of Babylon, may have inspired the story of the Garden of Eden. According to Genesis, the first cities founded in Shinar after the flood were Babel (Babylon), Erech (Uruk), and Accad (Akkad), while the first cities in Assyria (northern Iraq) were Calah (Kalhu, now Nimrud) and Nineveh. With the exception of Akkad, well-

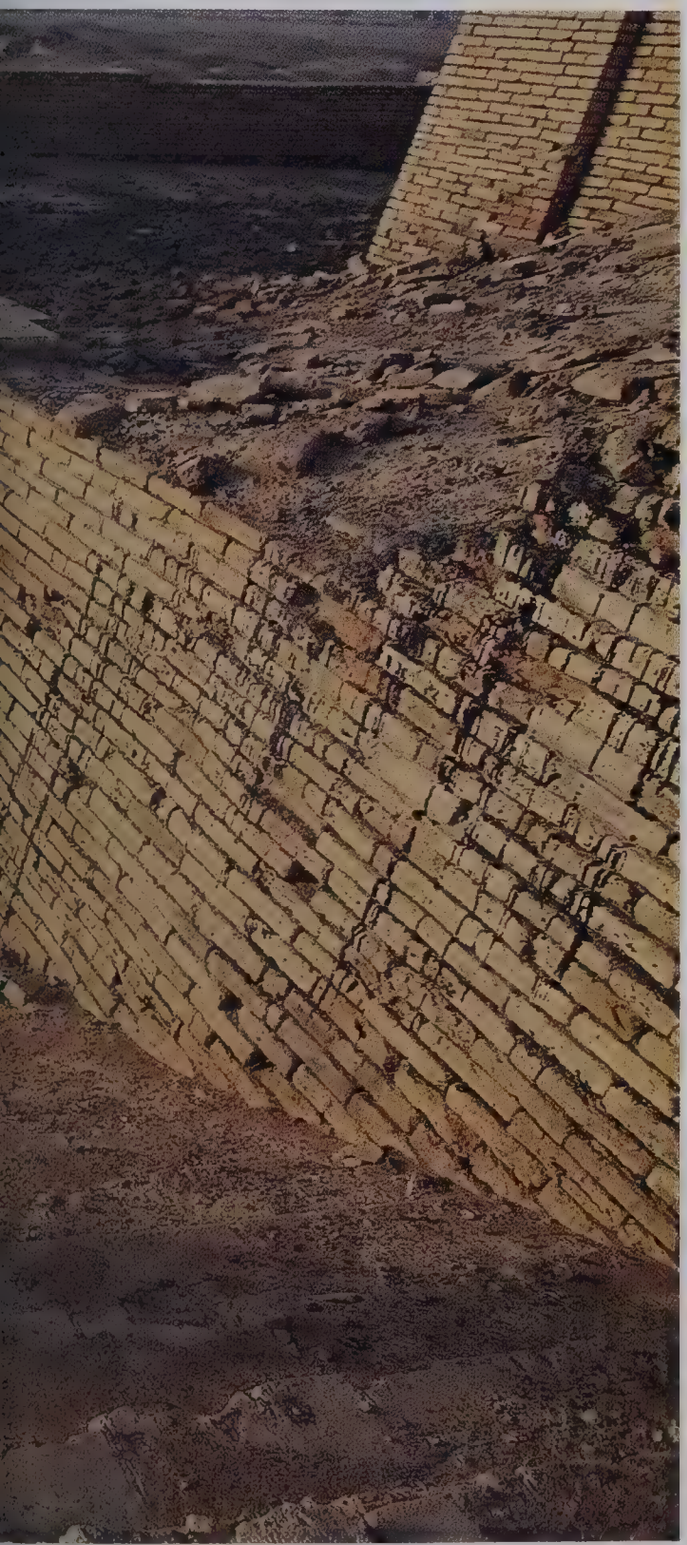
preserved remains of all these cities can be seen in Iraq today.

Archaeologists were relatively slow to tackle the region's countless tells, the earth mounds that mark the sites of ancient settlements. Consisting largely of the accumulated remains of mud-brick buildings, they were less enticing than the standing stone ruins of ancient Egypt, Greece, and Rome, and their historic identity was not always apparent, even to local inhabitants. The first archaeologists to explore them were Paul-Émile Botta, a French diplomat, and Austen Henry Layard, an adventurous English lawyer. In the mid-nineteenth century they both probed mounds in and near present-day Mosul, a city in northern Iraq that embraces the site of ancient Nineveh. Between the two of them, they uncovered the remains of five Assyrian palaces.

One, excavated by Layard in Nineveh, was the "palace without rival" of Sennacherib, a king of the Assyrian empire. The inner walls and courtyards were lined with two miles of sculptured stone

Dating from about 2100 B.C., Ur's ziggurat, or stepped tower, was excavated in the 1920s and 1930s.

slabs depicting the king's various campaigns, from the Persian Gulf to the Mediterranean. Sennacherib is best remembered for his unsuccessful siege of Jerusalem in 701 B.C. The siege was cut short, according to conflicting biblical accounts, either by the angel of the Lord or by a large bribe paid by the Judaean king. An inscription on a statue found in the doorway of Sennacherib's throne room also recounts the bribery tale, providing the first-known independent written account corresponding to a story in the Bible.



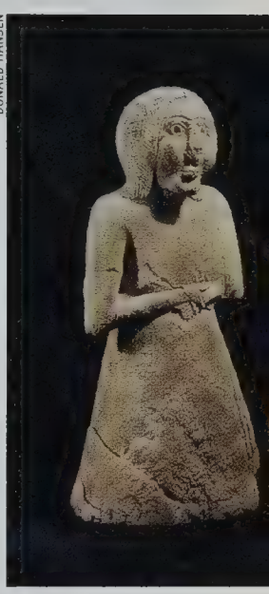
Within the palace Layard discovered thousands of clay cuneiform tablets, constituting the world's earliest-known comprehensive collection of written knowledge. In 1872 George Smith, a young Assyriologist at the British Museum, discovered that one of these tablets told the story of a great flood that had covered Earth. Suddenly it appeared that eyewitness accounts might be able to enrich the entire biblical narrative, if only the right tablets could be unearthed. This prospect precipitated a refocusing of archaeological attention in the last quarter of the nineteenth century—from art to tablets and from northern to southern Iraq, the setting of Genesis. Although little direct evidence for the historicity of the biblical accounts emerged from these excavations, they did reveal a previously unknown civilization that had profoundly shaped the biblical texts.

At Ur, the reputed birthplace of Abraham, excavators discovered a temple complex and royal tombs packed with gold treasures.

At the turn of the twentieth century, German teams initiated extensive excavations at three major sites: Babylon, Ashur, and Uruk. In about 1750 B.C., Babylon was the capital of an empire under Hammurabi, a king whose law code recorded principles of justice still recognized today. More than a thousand years later, Babylon became the capital of an even greater empire under King Nebuchadrezzar II (Nebuchadnezzar), who reigned from about 605 to about 561 B.C. and is traditionally credited with establishing the Hanging Gardens of Babylon, one of the Seven Wonders of the World. The Tower of Babel, the great ziggurat beside Babylon's temple of Marduk, dates to this era. Its foundations are visible today. Babylon was also famous for its city wall, part of which—the polychrome brick Ishtar Gate—was carried off to Berlin by the German excavators. Two earlier versions of the gate, adorned with bulls and dragons in brick relief, still stand at the site.

In 587 B.C. Nebuchadrezzar II captured Jerusalem and herded its population east to Babylonia. Some biblical scholars believe that, after arriving in Babylon, the captives drew on the traditions of their conquerors to compose the story of a people that originated in Eden, survived the Flood, built the Tower of Babel, and then, in the person of a

DONALD HANSEN



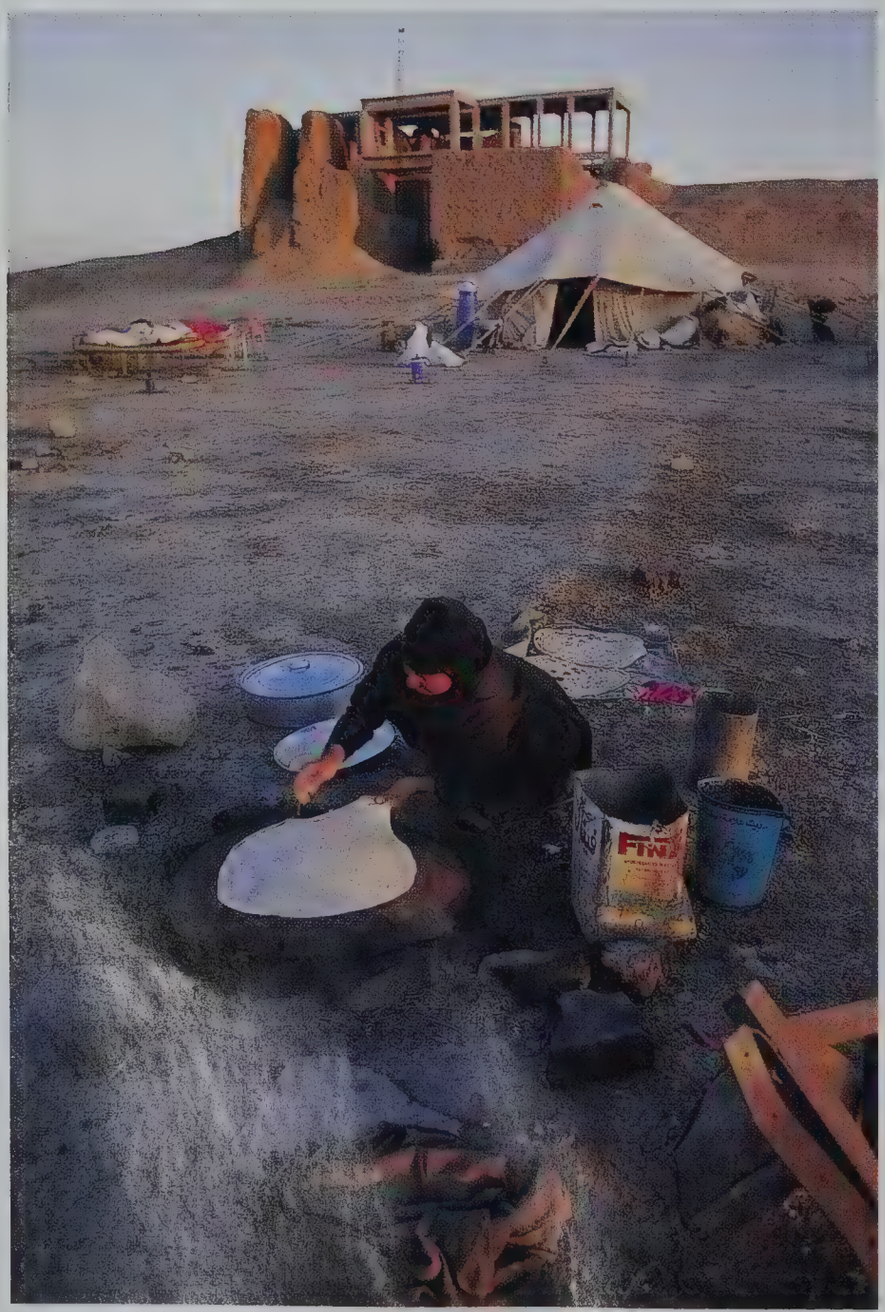
A limestone statuette discovered in the Inanna Temple of Nippur depicts a woman with her hands clasped in worship. The figure was stolen from the Kirkuk regional museum in northern Iraq following the Gulf War and is still missing.

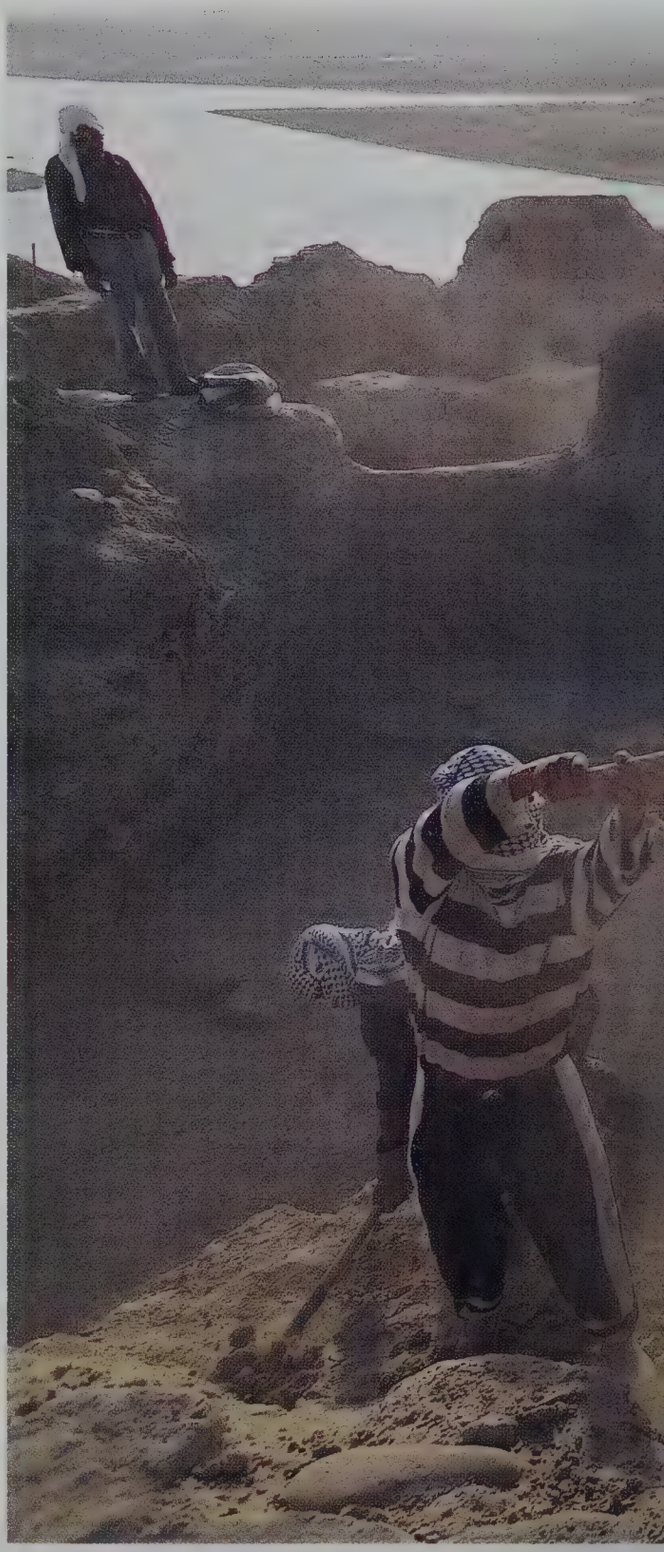
great patriarch, migrated westward to Israel. Abraham's journey became a source of inspiration for the exiled Judaeans.

The ancient city of Ashur, on the Tigris River in northern Iraq, gave its name to the god, the land, and the people of Assyria. Early in the second millennium B.C., Ashur grew wealthy through trade with Turkey, later becoming the center of an empire that encompassed all of what is now Iraq, Syria, Lebanon, Jordan, Israel, and Egypt, as well as large parts of Turkey and Iran. At Ashur the German excavators uncovered monuments and documents from the entire span of Assyrian history.

Uruk, in southern Iraq, often considered the world's first true city, is the place where writing first appeared. Its legendary king, Gilgamesh, is the subject of the oldest-known epic story, in which he

A woman makes bread in a bedouin camp at Nineveh, below. Behind her is the restored Nergal Gate, straddling the ruins of the city wall. Opposite page, bottom: An ivory furniture ornament from Kalhu, now in the Iraq Museum.





During the bombing of Baghdad, artifacts in the Iraq Museum were dispersed for safety to regional museums and to the vaults of the Central Bank. But the bank was bombed, and after the cease-fire, the regional museums were looted.

fails in his quest to elude death but achieves immortality by building Uruk's great city wall. So complete was the city's economic dominance of Mesopotamia from about 3500 to 3000 B.C. that mosaics made of baked clay cones, a feature considered evidence of an Uruk administrative or mercantile presence, are found from Turkey to Egypt. While the German archaeological work

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was permanently cut short at Babylon and Ashur by World War I, it was resumed at Uruk prior to World War II and again in 1953. Over the course of a century of excavations there, the German team has recovered more evidence for the rise of Mesopotamian civilization than is available from any other site. Discoveries there include early evidence of kingship

At Ashur, on the Tigris River, above, the Iraqi Department of Antiquities and Heritage has launched new excavations, in part to discourage looters.

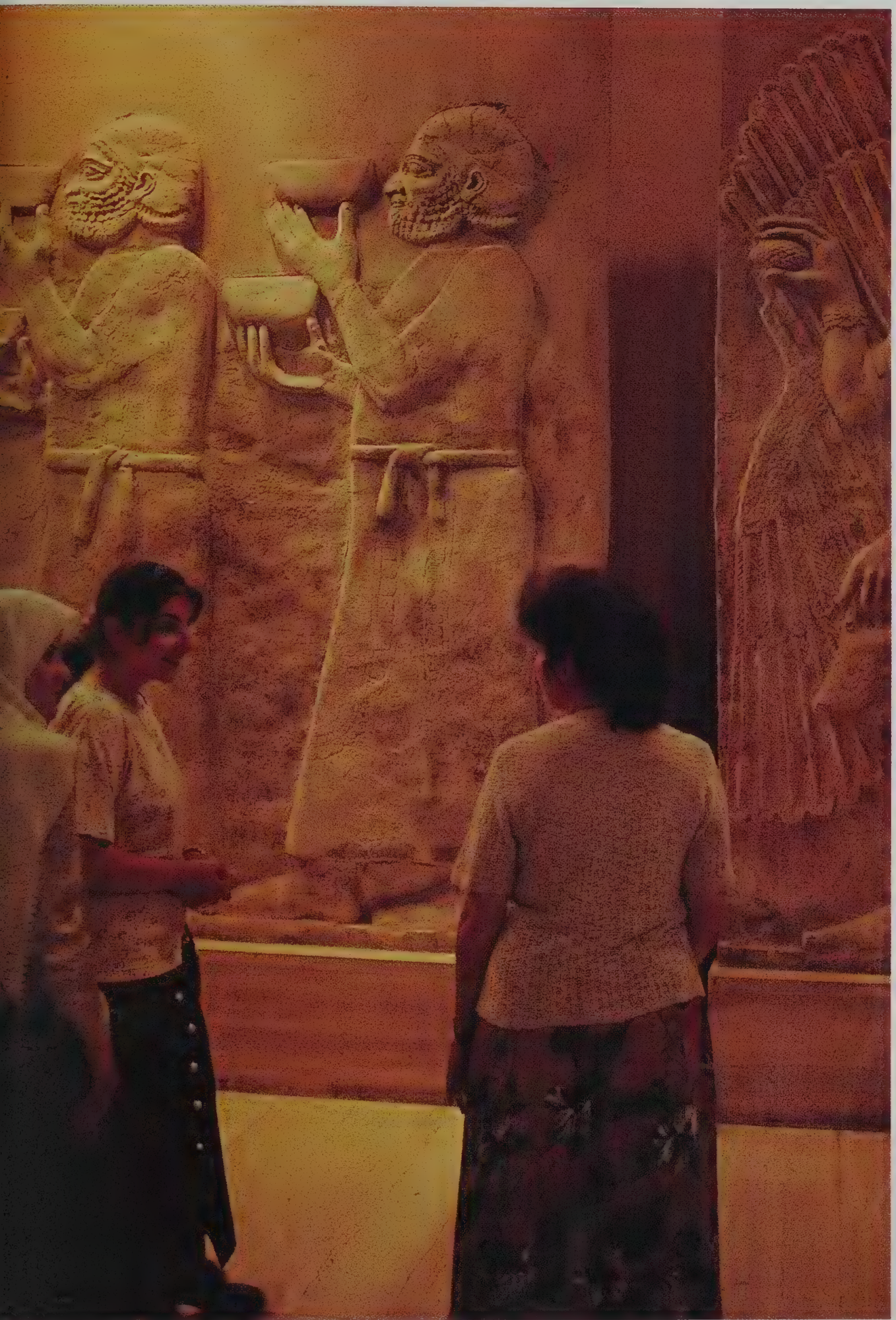
and monumental architecture and clear representations of religious rituals.

Prior to World War I, the area that is now Iraq was part of the Ottoman Empire. The excavations of Layard, Botta, and other foreign archaeologists in

The earth mounds that mark the region's ancient sites were less enticing to archaeologists than were the stone ruins of Egypt, Greece, and Rome.

the nineteenth century were carried out under permits issued by the government of the Ottoman sultan in Istanbul. At first the sultan showed little interest in ancient remains, and excavators in the mid-nineteenth century were allowed to export whatever they wished. This is when the British Museum and the Louvre acquired the bulk of their renowned Mesopotamian collections, which aroused

MYRA KLOCKENBRINK



VANNI: ART RESOURCE, NY

At the Iraq Museum in Baghdad, left, students view reliefs from Dur Sharrukin. Above: Babylon's Ishtar Gate, unearthed by German archaeologists before World War I, is displayed in Berlin's Pergamon Museum.

Built of unreinforced brick, an arching vault at Ctesiphon, right, is all that remains of a sixth century A.D. audience hall, constructed when Iraq was part of Iran's Sāsānian Empire. Below: A winged deity that once guarded a palace

ERICH LESSING; ART RESOURCE, NY

door. Discovered at Dur Sharrukin, the alabaster relief was acquired by the Louvre in the 1850s.

great scholarly and public excitement. Stung by the loss of irreplaceable treasures from the empire and anxious to establish Istanbul as a center for the study of ancient art, the Ottoman statesman Hamdi Bey founded the Archaeological Museum of Istanbul in 1881. Thereafter, foreign archaeologists were obliged to share their discoveries with the museum, which divided duplicate finds with the excavators and had the right to retain unique pieces.

After World War I, Iraq became a separate state administered by Britain. With the energetic guidance of a British official, Gertrude Bell, who advocated that antiquities be retained by the country of origin, the Iraq Museum was founded in 1923 in Baghdad. Upon the end of the British mandate in 1932, Iraq began to take charge of its own patrimony. An antiquities law enacted in 1936 decreed that all the country's antiquities more than 200 years old, whether movable or immovable, above ground or below, were the property of the state and that none could be excavated, sold, or exported without government authorization. Initially, the Ottoman tradition of dividing duplicate finds with their excavators was still permitted, but amendments to the law in the 1970s eliminated this provision.

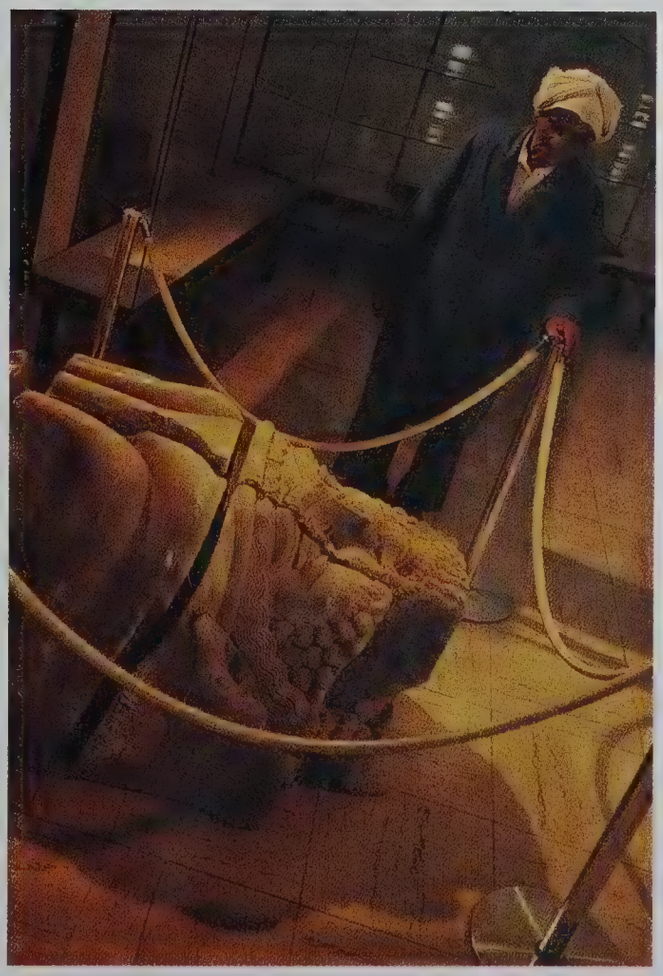
Artifacts from archaeological sites were now housed in the Iraq Museum, in the heart of downtown Baghdad, which accumulated the most important collection of Mesopotamian antiquities in the world: gold from Ur, ivories and gold from Kalhu, thousands of clay tablets, and major works of sculpture from all periods. The Iraqi Department of Antiquities and Heritage created a nationwide pro-

gram to educate the populace about their country's cultural history. The centerpiece was a network of regional museums, each of which displayed hundreds of objects chosen to provide a microcosm of Iraqi heritage. Largely as a result of the enthusiasm and cooperation engendered by this program, the plundering of archaeological sites was rare.

At the time of the Gulf War, archaeology was experiencing an extraordinary revival in Iraq, after a dry spell during the nation's 1980–88 war with Iran. Dozens of foreign and Iraqi teams were working at an unprecedented rate, often in response to threats posed by modern urban and agricultural development. At the ancient site of Sippar, just southwest of Baghdad, Iraqi archaeologists had discovered an extensive library from the late Babylonian empire. A wide variety of clay tablets (literary works, omens, incantations, astronomical records, mathematical exercises) were found, still arranged on the shelves. British and Polish teams in northern Iraq were excavating Nemrik, Qermez Dere, and M'lefaat, three of the oldest villages in the world. (These settlements, dating to about 8000 B.C., were contemporary with the first domestication of plants and animals for subsistence purposes.) And at least five American teams had recently renewed or initiated fieldwork at the sites of Nippur, Lagash, Mashkan-Shapir, Dilbat, and Nineveh. Knowledge of Iraq's past was increasing exponentially.

Robbers chopped off the human head of a colossal winged bull and sawed it into eleven pieces in an attempt to smuggle it abroad.

When Iraq invaded Kuwait in the summer of 1990, virtually all archaeological activity ceased, and the war and subsequent imposition of UN sanctions have left Iraq's patrimony in peril. Not only is almost no money available for the preserva-

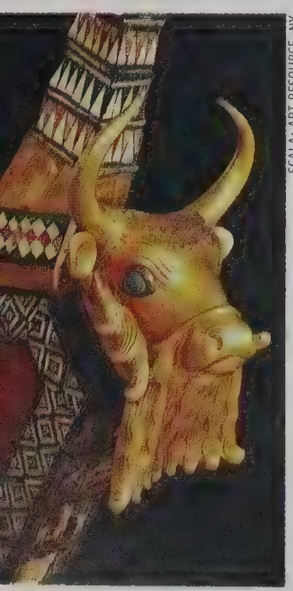


Hacked into pieces by plunderers of Dur Sharrukin, the human head of a winged bull, left, now rests in the Iraq Museum. Above: A guard shepherds visitors to Umma, a site heavily looted after the war.

tion of antiquities, but in addition, some Iraqi citizens, squeezed between ruinous inflation and shortages of basic necessities, have turned to looting and selling artifacts from excavated and unexcavated sites and even from museums. In the past few years, for example, robbers have hacked up the sculptured stone slabs from the palace of Sennacherib, which had been reconstructed as a museum in the 1960s, and some of the best-preserved fragments have been smuggled abroad to satisfy collectors.

Another affected site is Dur Sharrukin (modern Khorsabad), where Botta discovered the palace of the Assyrian ruler Sargon II (reigned 721–705 B.C.). Before the Gulf War, little of the building itself remained standing, and its monumental sculptures were on display in Baghdad and Paris. Immediately prior to the war, however, Iraqi archaeologists had excavated a colossal human-headed winged bull from one of the city gates. A few years later, robbers chopped off its head and sawed it into eleven pieces in an unsuccessful attempt to smuggle it abroad. The mutilated remains are now on display in the Iraq Museum, and ten of the perpetrators are reported to have been executed.

A bull's head decorates a lyre that was excavated from one of the rich burials in the royal cemetery at Ur and that is now in the Iraq Museum.



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At Kalhu, Layard excavated the site of the palace belonging to King Tiglath-pileser III (reigned

One of the tablets told the story of a great flood that covered Earth. Might eyewitness accounts exist to enrich the biblical narrative?

744–727 B.C.). The building had been dismantled by one of the king's successors, and its sculptured wall slabs stacked neatly in preparation for recarving. Recently, many of the slabs were stolen and cut up into smaller pieces, which are now appearing on the international art market. The fate of more than a hundred pounds of gold jewelry and other fabulous artifacts that Iraqi archaeologists excavated just before the Gulf War from the burial sites of four Assyrian queens remains unknown.

The site of Telloh ("the mound of tablets"), excavated by French archaeologists beginning in 1877, was the cult city Girsu in the ancient city-state of Lagash. Among the cuneiform records found there is an inscribed stele (upright stone slab) from about 2500 B.C. that constitutes the earliest known documentation of state-sponsored warfare. Lagash was competing with neighboring Umma for irrigation rights, and the dispute was settled by armies that rode into battle in war wagons, among the earliest documented wheeled vehicles. After the Gulf War, Telloh was apparently plundered, because previously unknown temple records from the site appear regularly for sale on the Internet.

Lagash's rival, Umma, unexcavated before the war, recently fell prey to wholesale looting, resulting in large numbers of tablets from the site being offered on the antiquities market. In response, the Iraqi Department of Antiquities and Heritage initiated its own excavations at Umma and last year discovered a monumental palace or temple and a huge cemetery, described by the excavators as "a city of graves"—all dating from about 2500 B.C. Perhaps a

stele with Umma's version of the war with Lagash will eventually come to light.

During the bombing of Baghdad, the Iraq Museum was closed and its holdings dispersed for safety to the regional museums and the vaults of the Central Bank in Baghdad. The unanticipated sequel was that the bank was bombed, and during the uprisings that followed the cease-fire, at least seven of the regional museums were looted. The full extent of the losses is not yet known; however, some 4,000 objects have been reported missing from the regional museums. Last year the Iraq Museum reopened, but it may take years to evaluate and conserve the collections. Rebuilding the professional staff, diminished by hardships and cutbacks, is a major challenge, because the education of the upcoming generation has been disrupted.

Arguing that Iraq has not fulfilled the terms imposed by the cease-fire, the United States has consistently used its UN Security Council veto to maintain the sanctions. As a result, over the years, most kinds of nonhumanitarian assistance to Iraq have been blocked, including a planned UNESCO mission to assess damage and even a request to import photographic supplies to reproduce images of stolen artifacts for Interpol. The Department of Antiquities and Heritage has managed to protect and document a few major sites and to reopen the Iraq Museum, but for the most part, we are witnessing the destruction of a very promising past. Once gone, it can never be recovered. □

At Kalhu, in the throne room of King Ashurnasirpal II, archaeologist Mehti Baba points to an image of the king.

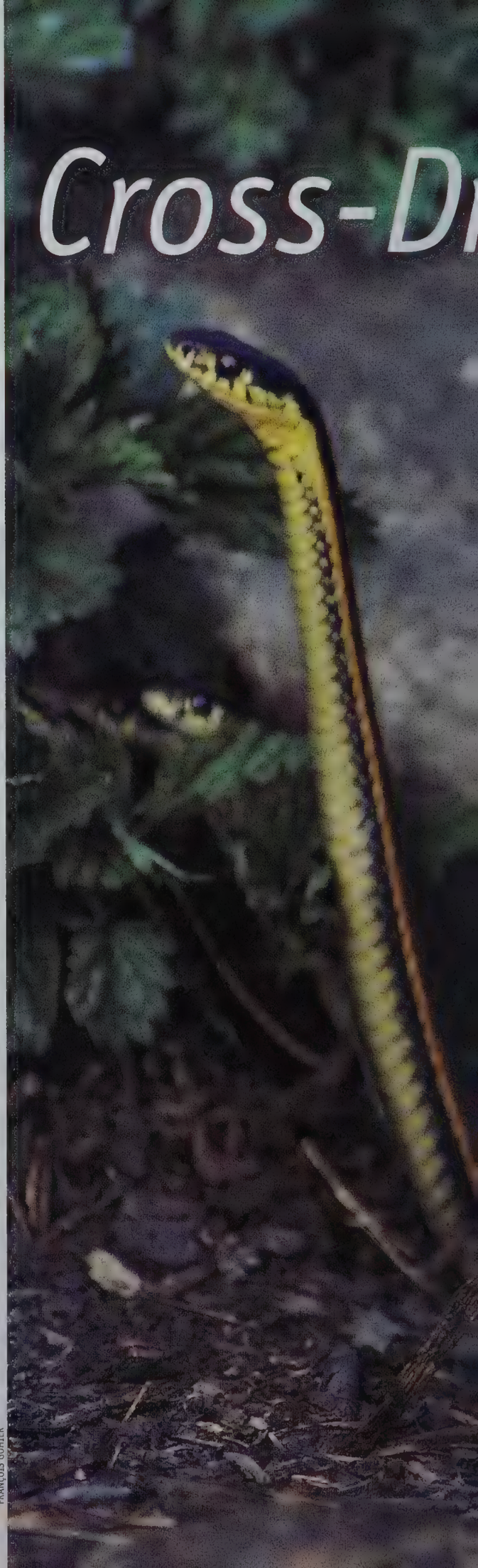
Serpentine Cross-D

Some male Manitoban garter snakes wear the alluring scent of females.

By Richard Shine and Robert Mason

Garter snakes may be the most common snakes in North America, but the subspecies known as the red-sided garter snake provides an uncommon annual spectacle. During the severe, six- to eight-month winters in Manitoba, Canada, these small, nonvenomous snakes sequester themselves in deep crevices to avoid freezing. Since such sites are rare in the barren, rocky region between Lake Manitoba and Lake Winnipeg, snakes that have dispersed across many miles in the summer gather by the thousands to spend the winter at the few suitable spots. Some of their major dens are located about seventy-five miles north of the city of Winnipeg and are surrounded by swampland that during the warmer months provides an abundance of frogs, the snake's favorite prey. When dens near swampland empty out in early spring, some of them disgorge more than 10,000 snakes from rocky depressions as small as sixteen feet long and six feet wide.

Over the past fifteen years, one of us (Bob Mason) has been visiting these dens in an attempt to understand the snakes' behavior. Males and females mass together in the same dens, emerging from hibernation between late April and the end of May. (In dens that receive more sunlight, the exodus can take place somewhat earlier.) Males emerge first. Having reached the surface, they stay close to the den for the better part of May. It's now mating season, and they're waiting to intercept the tardy females. As soon as a female appears, a seething ball of dozens (often hundreds) of amorous suitors forms



FRANÇOIS GOHIER

Seemingly charmed by the spring sunshine, dozens of red-sided garter snakes emerge from their winter den in Manitoba's Interlake region.

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MYRA KLOCKENBRINK

around her. This rippling clot of snakes may move en masse over rocks and vegetation until the female has mated. Some "mating balls," however, contain no females. In 1985 Bob Mason, working with David Crews, of the University of Texas, reported that frenetic males frequently attempt to mate with certain other males that they evidently mistake for females. These "she-males," they observed, are indistinguishable in size and markings from ordinary males, and they also seek female mates—yet they attract other males by the score.

Female mimicry by males, although not common, occurs throughout the animal world. Among some anole lizards, for instance, males that are too small to defend a territory of their own may manage to live within a dominant male's territory if they can avoid conflicts by passing as females. Common sunfish produce two kinds of males—a large, dominant male that builds and defends a nest and tries to attract females to it, and a smaller male that resembles, and behaves like, a female. This female mimic swims between a mating pair just as the dominant male is about to fertilize the female's eggs and fertilizes some of them himself.

Manitoba's red-sided garter snakes, however, are the only snakes known to have males that mimic females. How does an amorous male garter snake tell a male from a female in the horde of snakes emerging in early spring from a large den? By sensing the pheromones that emanate from the animals' skin. When snakes flick their tongues in and out, they pick up chemical cues from the air, which they transfer to a sensory organ in the roof of the mouth. When a male tongue-flicks another snake, he instantly determines his neighbor's apparent gender by the scent of the lipids on its skin. Bob and David discovered the pheromone differences during their first year of collaboration, and a few years later they were able to synthesize the signaling chemical in the lab.

Why do some males smell like females? At first the researchers hypothesized that a male's release of female chemicals might benefit him by confusing his rivals: the she-male would be the only male snake within a mating ball that knows who the real females are. At this stage of the game, Bob and David also thought that individual snakes remained either she-males or he-males throughout an entire mating season, if not an entire lifetime. There the story remained until Rick Shine came from Australia in 1997 to visit Bob at the garter snake dens. Rick became so intrigued with the abundance of female mimics he saw there that he returned the following year with two research assistants from the

Garter Snake Grottoes

Each spring in central Manitoba, tens of thousands of red-sided garter snakes *(Thamnophis sirtalis parietalis)* emerge from their rocky dens in the bleak countryside between Lake Winnipeg and Lake Manitoba. The mass emergence attracts busloads of schoolchildren and tourists from southern Manitoba and beyond. On Mother's Day, Winnipeg youngsters traditionally take their moms on excursions to view the springtime fertility spectacle. While many residents of the towns of Inwood, Narcisse, and Chatfield view with fascination the garter snakes' migrations, others wish the snakes would gather elsewhere. One summer, according to local residents, a young couple built a house over a rock crevice that they thought would make a perfect natural cellar. When autumn arrived, so did a few thousand garter snakes, returning to their traditional winter den. The couple soon decided they had better relocate their home to a less snaky location.

Until the early 1980s, some local collectors scooped up thousands of the snakes and sold them to pet dealers in the United States, England, and Germany. Scientists and wildlife officials became concerned, and in 1988 commercial collecting was banned, but many snakes were still being killed in traffic as they crossed a major highway near the Narcisse dens. Last year the Manitoba Department of Natural Resources (now the Manitoba Department of Conservation) installed a series of pipes under the road. But how to get the snakes to use them? Bob Mason's experiments showed that if garter snake pheromones were applied to the floor of the culverts, the snakes would follow the chemical trails. The technique is working: this fall thousands of garter snakes crossed safely under the highway.—*R. M. and R. S.*

FRANÇOIS GOHIER

In early May, masses of garter snakes, left, pour out of a rocky den in Manitoba. Males may linger near a den's entrance for days, waiting for the later-emerging females. Below: A newly emerged snake gapes as it takes in the first fresh air it has breathed in months.

FRANCOIS GOHIER

University of Sydney, specifically to study the she-males, and our collaborative attack on this puzzle got under way.

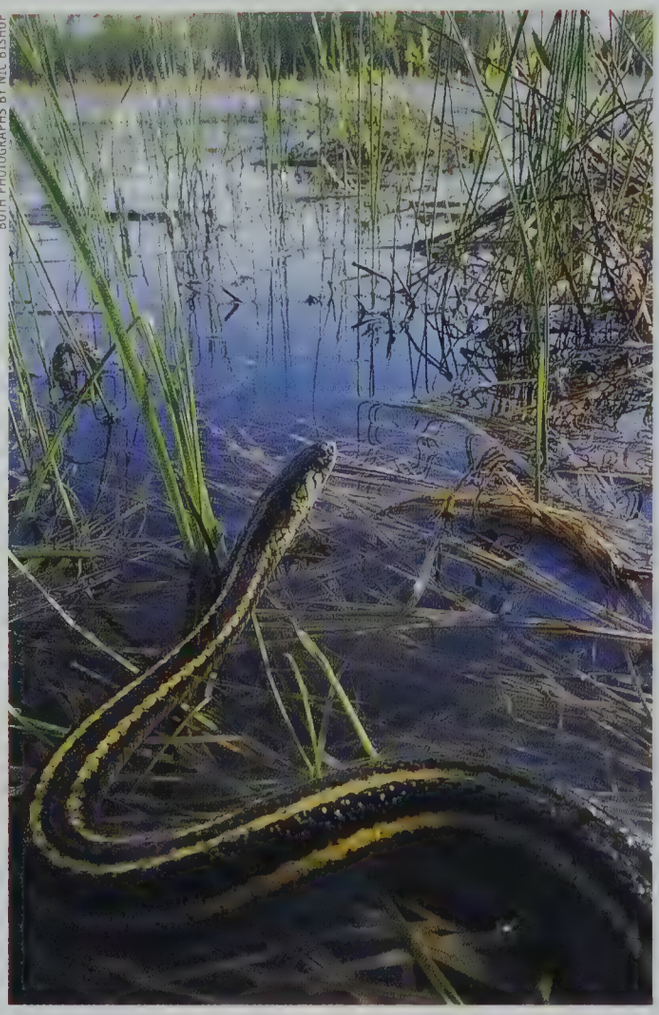
First we attempted to quantify the attractiveness of individual snakes. Holding various "target" snakes by the tail, we crouched in the grass near a den and placed them in front of mate-searching males. We then recorded the mate-searchers' level of interest. Responses ranged from ignoring the target or rapidly flicking the tongue to aligning the body with that of the presented snake and trying to mate. With this simple method, we were able to confirm that she-males (which we had extracted from the center of mating balls) were indeed very attractive to ordinary males, though a bit less so than real females. Indeed, the she-males proved to be attractive to one another and sometimes even to themselves. (If a she-male accidentally encountered part of his own body, he might spend quite a bit of time busily courting himself!)

She-males proved to be attractive to one another and sometimes even to themselves.

Next we investigated how she-maleness is produced. Did she-males obtain their coating of female pheromones through physical contact with true females, perhaps by rubbing against them during courtship? We soon discovered that even if we vigorously rubbed a he-male against a female, he remained unattractive to other males. We concluded that when males were attracted to she-males, they were reacting not to rubbed-on chemicals but to those naturally produced in the skin.

To learn more about how individual snakes react to she-males, we set up several nylon enclosures about three feet square near a den. We captured a number of she-males, he-males, and females, kept them in separate cloth bags overnight, and placed various combinations of snakes in the nylon pens the next day. To our astonishment (and initial dismay), although a few of the she-males we had collected the day before continued to elicit some interest from ordinary males, most had lost their allure. In other words, we had found that a she-male could switch its sexual identity within a twelve-hour period. Needing to ascertain that stress wasn't the cause of our captive snakes' unnatural behavior, we decided to return to a den to confirm this finding in free-ranging snakes.

This time we simply collected, measured, and examined a large sample of she-males and he-males, looking for characteristics that might give us a clue



BOTH PHOTOGRAPHS BY NIC BISHOP

In a swamp, right, a famished snake can dine on frogs after emerging from a long hibernation. Below: A young snake, stirring after its winter retreat, surveys the spring landscape.

to what was going on. Searching through hundreds of snakes clustered around the entrance to the den, Rick identified mating groups and examined each she-male and its ball of suitors. Eventually he spotted a pattern that had escaped prior observation. Most of the he-males were bright, glossy animals, but the she-males were often dull and dirty with grit. Once we recognized this fact, we had to account for it. The explanation, we thought, might be that she-maleness was all about the timing of reproduction in relation to hibernation. Perhaps it was a transitory phase that most—or perhaps all—male garter snakes passed through soon after they emerged from the den.

Indeed, since the same dirt can be seen on most females when they first reach the surface, the grit we observed on the she-males suggested that they, too, had just emerged from underground. And according to our measurements, the she-males were somewhat chubbier than the he-males. This was consistent with our "recent emergence" hypothesis, since we knew from studies of recaptured males that they rapidly lose weight during their frantic mate-searching and courtship activities. The hypothesis also fit in with Bob and David's original, and apparently paradoxical, finding that she-males tend to have a high testosterone level, since another recent study had shown that testosterone levels in male garter snakes are highest at emergence and fall off rapidly thereafter.

We further tested the idea by marking males as soon as they emerged. Sure enough, the marked males were she-males for a day or two and then rapidly reverted to he-maleness. So part of the puzzle was solved, but many others remained. One idea we considered was that hibernation could weaken the animals and that it might take a day or two for males to recover their strength and prepare for the frantic activity of mating. The huge numbers of emerging snakes allowed us to test the hypothesis that she-maleness is related to a recovery period. Indeed, our paint-marked she-males were weak and lethargic during the first day or two after emerging but began to move around actively at about the same time they switched off their production of female pheromones. We measured their strength by clipping their tails to a spring balance and letting them pull against it; she-males proved to be weaker than same-sized he-males. We measured their crawling speeds in a circular arena with a diameter of twelve feet and a circumference ringed with empty beer cans. After placing a snake at the center and prodding it, we recorded how long each one took to reach the edge of the circle. Again, the data confirmed the prediction: she-males moved much more slowly than he-males.

She-males tried to mate with females, but they were not very good at it.

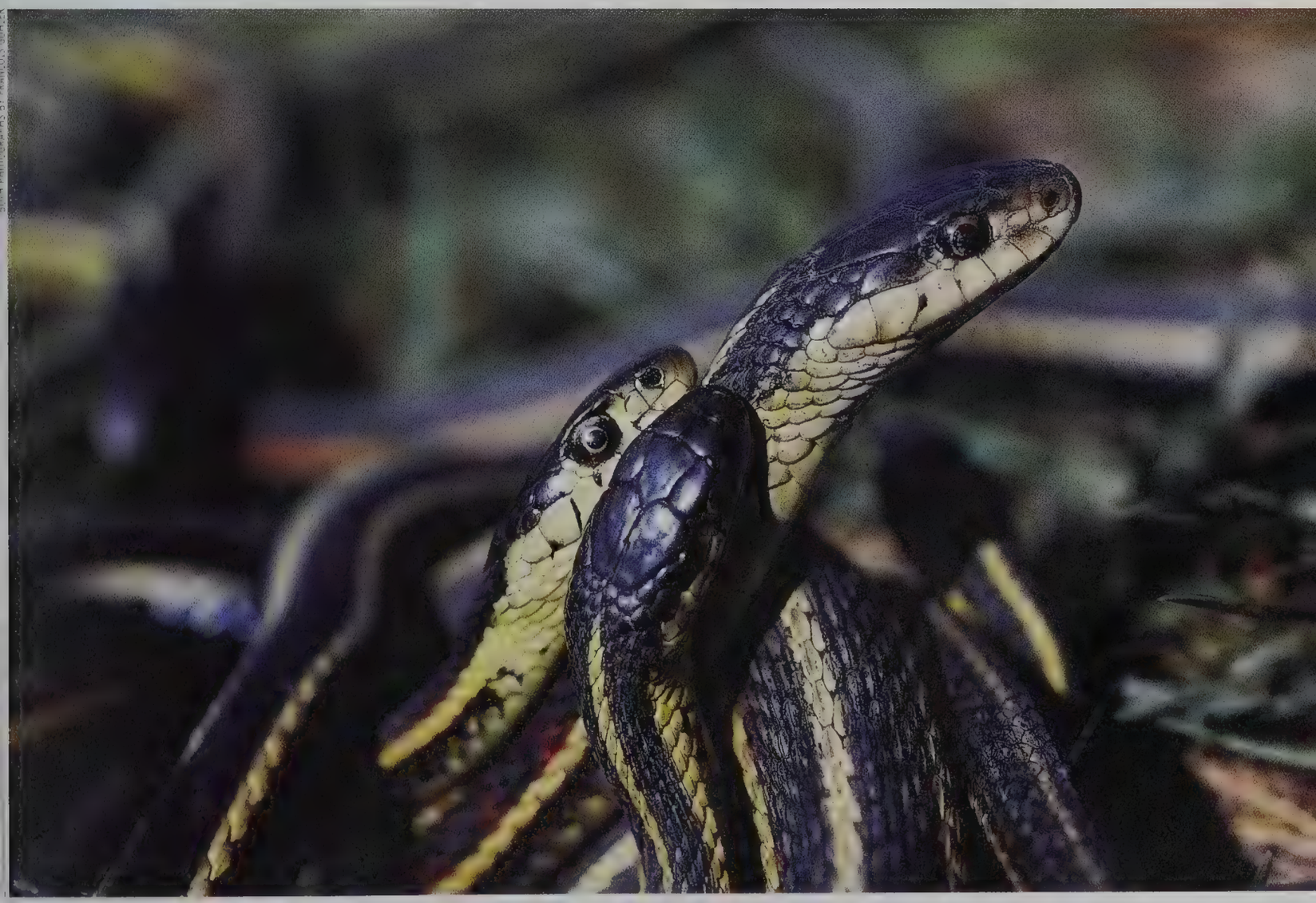
If she-males are slow and weak, how good are they at courtship and mating? Again, we used the nylon enclosures to explore this question. When we put a she-male together with a female, it took him almost twice as long to persuade her to copulate as it did for a he-male to mate with a female in an adjacent pen. Whenever we put she-males and he-males together and then added a female, it was almost always one of the he-males that succeeded in copulating with her. She-males were indeed prepared to mate with females, but they were not very good at it, because they had not yet recovered from their long winter's inactivity.

In spite of all we have learned about these

snakes, we still don't really know why male garter snakes mimic females when they first emerge from hibernation. Perhaps such mimicry helps draw their rivals' attention away from newly emerged females and buys them time to recover their full strength. Mimicry would thus both prevent she-males from wasting energy on half-hearted attempts to mate and encourage other males to expend energy and sperm on fruitless courtship. In another recent study, we found that she-males seem to assess their chances of mating, and if many large and healthy he-males are vying for the same female, the she-males do not attempt vigorous courtship.

The more questions we answer about these ubiquitous little reptiles, the more new questions arise. When one first peers into a Manitoban den and sees thousands of red-sided garter snakes writhing around—looking for all the world like live spaghetti—their behavior appears chaotic. But we have come to appreciate that these animals behave with extraordinary subtlety. What we have learned about males distracting their fellows by wearing feminine perfume may be just the first step toward elucidating one of nature's more intriguing mating systems. □

Dozens of male garter snakes create a mating ball, left, by surrounding a single female—or perhaps a she-male. Two males, below, try to align their bodies with a chubby she-male as they compete to mate with it.



A Man and His

Capistrate à longue queue.

HAND-COLORED LITHOGRAPH FROM *HISTOIRE NATURELLE DES MAMMIFÈRES,* BY ÉTIENNE GEOFFROY SAINT-HILAIRE AND FRÉDÉRIC CUVIER. MEGAN CARLOUGH; AMNH.

Menagerie

By Richard W. Burkhardt Jr.

Frédéric Cuvier

"The menageries that have existed up to the present have always been regarded as institutions of extravagance rather than institutions of utility." So wrote Frédéric Cuvier in 1804, introducing his guidebook to the new menagerie of the National Museum of Natural History in Paris. No one in France at the time would have doubted his claim. The royal menagerie at Versailles, established in the seventeenth century by Louis XIV, had long been notorious for its wastefulness, and just prior to the Revolution, while the French people struggled to keep themselves from starving, it was alleged that a dromedary (some said an elephant) at Versailles was treated to six bottles of burgundy a day.

What would a truly useful menagerie be like? This question arose in the early years of the Revolution, at the same time that the future of the old Jardin et Cabinet du Roi (the king's botanical garden and natural history collection) hung in the balance. Jacques-Henri Bernardin de Saint-Pierre—

Shortly after the French Revolution, a young chemist and naturalist became the world's first scientific superintendent of a national, public zoo.

an author, a forerunner of the French romantic movement, and director of the garden from 1791 to 1793—suggested that a menagerie would allow one to observe the behavior of living animals, to acclimatize beneficial species from foreign lands, to cross domestic races, and to study the affinities between humans and animals. It would also serve a diplomatic function. When the powers of Africa and Asia made gifts of wild animals to the French nation (as was their custom), explained Bernardin, France had to be prepared to receive them properly. Killing the animals, or letting them die, and then exhibiting their skins or skeletons was obviously unacceptable. Bernardin therefore proposed that a new menagerie be established at the Jardin des Plantes (the politically expedient name for the place now that kings were out of style).

Frédéric Cuvier's interest in animal behavior encompassed small species, such as the North American fox squirrel (opposite page), as well as large.

In June 1793, by decree of the revolutionary government, the Jardin des Plantes and the Cabinet d'Histoire Naturelle were reconstituted as the Museum of Natural History. Its structure was democratic, its purposes utilitarian. Five months later, a menagerie became part of the establishment—but not as a direct result of Bernardin's earlier suggestions or of initiatives by the museum's new professor-administrators. During the Revolution and for decades before it, some people had made a living by exhibiting exotic animals on the streets of Paris. On November 3, 1793, the Paris police department, citing public safety, ordered that such animals be confiscated and "conducted right away to the Jardin des Plantes." It came as a complete surprise to the museum's professors when the police appeared at their gates the following day escorting a polar bear, a panther, a civet, a monkey, and the animals' ex-owner, who demanded to be compensated for his animals (and hired to care for them). Two days later, the professors found themselves confronting another polar bear, two mandrills, two agoutis, a tiger, a vulture, two eagles, and two more animal proprietors, who, like the first, were retained to care for the animals. The animals were kept in their cages and sheltered in an empty carriage house.

Other animals soon arrived in similar fashion, and the next spring, the four creatures still living at the Versailles menagerie—a lion, a dog that was the lion's companion, a quagga (a now-extinct relative of the zebra), and a spiral-horned African antelope called a bubalis or a cow of Barbary—were also transferred to Paris. While the antelope died almost immediately from injuries sustained during the move, the fraternal relations of the lion and the dog

BIBLIOTHÈQUE CENTRALE DU MNHN, PARIS

Exotic animals once exhibited by their owners on the streets of Paris were confiscated and brought to the city's Jardin des Plantes.

were presented to the public as a moral lesson in how a ferocious beast could, under the proper circumstances, come to live in harmony with an animal of another species.

From the beginning, the new menagerie was a great attraction to the public. For the professor-administrators of the museum, however, it was an ongoing headache. Both the animals and the animal keepers seemed to need a full-time supervisor. The worst offender was Félix Cassal, controversial guardian of *les animaux féroces*. Cassal was finally sacked in 1803 after scheming to have a fellow worker killed. Simultaneously (though independently), the professors agreed to create a new post within the museum hierarchy—*garde* (superintendent) of the menagerie—and chose Frédéric Cuvier for the position. Then thirty years old, Cuvier had a minor reputation as a chemist and some experience as a naturalist. Also (and certainly figuring significantly in his selection), he was the younger brother of Georges Cuvier, the museum's famous professor of comparative anatomy and one of the most powerful scientists in Napoleonic France. All at once, Frédéric Cuvier found himself occupying a place that had never before existed in the world of natural history: scientific superintendent of a national, public zoo.

Historically, what is particularly interesting about Cuvier's new post is that it complicated an ongoing debate among natural historians over who was best situated to speak authoritatively about the processes and products of nature. The debate assumed different forms in different contexts, but mostly it was waged between field naturalists on the one hand and cabinet naturalists, or museum specialists, on the other. Cabinet naturalists (Georges Cuvier, for example) maintained that only by working with collections of preserved specimens could one systematically compare the various products of nature and gain a full understanding of the similarities and differences among them. Field naturalists, by contrast, prided themselves on their familiarity with living animals and plants studied in the organisms' natural settings. Frédéric Cuvier found himself occupying a post that with respect to these two camps was neither fish nor fowl. Unlike a field naturalist, he would be observing his animals within the confines of a metropolitan zoo; unlike a cabinet naturalist, he would have the task of caring for and studying animals that were alive and kicking—and in some cases quite dangerous.

Indeed, Cuvier's new job did not promise to be easy. Now the guardian of more than a hundred mammals and nearly as many birds, Cuvier had virtually no place to turn for guidance. Who knew what sorts of shelters creatures from other climates needed to survive in northern Europe? How was one to feed them and keep them in good health? As *le garde* lamented in his 1804 guidebook, "There is practically no way of responding to these questions and a hundred others like them. Nothing has been written, nearly nothing has been seen, everything remains to be done." (He was no doubt exaggerating slightly, but having himself decried the wasteful royal menageries of the past, he was not

disposed to admit that useful things might have been learned at such places as Versailles or the Schönbrunn animal park in Vienna.)

He indeed had much to learn. Thanks to the efforts of naturalist voyagers, naval officers, colonial administrators, merchants, and other travelers, animals of all shapes and sizes would continue to arrive at the menagerie. From North America came squirrels and raccoons, bears and bison, eagles and an elk. From other corners of the globe came cockatoos, kangaroos, gerbils, jaguars, parrots, panthers, turtledoves, tapirs, mandrills, mongooses, and more.

The fraternal relations of a lion and its canine companion were presented to the zoo-going public as a moral lesson in living together harmoniously.

Beyond the question of caring for these exotic creatures was the issue of whether anything of value to natural history could be learned by studying animals in captivity. Many naturalists doubted it, but Frédéric Cuvier, the former student of chemistry, argued that menageries could be for zoologists what laboratories were for chemists. In one of his most optimistic moments, he suggested that zoo studies might one day render field studies unnecessary. Having learned the general faculties and dispositions of an animal from studying it in captivity, he said, the naturalist would be able to deter-

BIBLIOTHÈQUE CENTRALE DU MNHN, PARIS

Early problems at the zoo included animal keeper Félix Cassal, right, who was fired for planning the murder of one of his coworkers.

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mine "even in advance" how others of its species would act in their native surroundings.

A number of obstacles stood in the way of the younger Cuvier's plans, however. For one thing, the museum was run by its professors, and not only was Frédéric Cuvier not a professor, but his brother Georges advised him that aspiring to become one would be inappropriate as long as Georges remained a professor there. Occupying the position of superintendent, Frédéric lacked the authority to develop and teach a course on his subject. In addition, he was officially subordinate to Étienne Geoffroy Saint-Hilaire, the museum's professor of birds and mammals, with whom his relationship progressively deteriorated during the 1820s—a casualty of clashes between Geoffroy and the elder Cuvier over Geoffroy's bold claim that all animals were built on a single plan.

In his most optimistic moments, Frédéric Cuvier thought that studying the behavior of captive animals might render fieldwork unnecessary.

The living conditions of the animals in the menagerie also posed problems for Frédéric Cuvier. The quarters were often so confining and the

ALL IMAGES ON THESE PAGES FROM *HISTOIRE NATURELLE DES MAMMIFÈRES*. MEGAN CARLOUGH: AMNH.

Merchants and other travelers sent animals of all sizes and shapes to the menagerie: porcupines and parrots, tigers and turtledoves, gerbils and jaguars.

Cuvier was impressed by the trainability of seals, above right, as well as by their behavioral rigidity: accustomed to eating sole, one animal starved to death rather than eat anything else.

daily routines so monotonous that the animals failed to display the full range of their habits or abilities. Writing of the menagerie's raccoons, for example, Cuvier acknowledged that to know what they were fully capable of, "it would be necessary to see them under other conditions, that is to say sufficiently free and under circumstances sufficiently diverse, so their faculties could be in some measure developed."

Even when one of the animals displayed interesting behavior, keeping it alive long enough to study it thoroughly was frequently a problem—at least for Cuvier. The death of a menagerie animal was rarely perceived as a setback by the museum's other zoologists, since their work began when they were presented with creatures that were no longer living. Deaths at the menagerie were a major source of specimens for the cabinets of comparative anatomy and natural history. As for births, these were treasured events; many exotic species displayed a reluctance to mate or failed to reproduce under the conditions of captivity.

Undeterred by the problems confronting him, Cuvier remained optimistic, ambitious even, convinced that the study of living animals in the menagerie had much to offer. He believed that it should be possible to study not only such topics as hybridization and acclimatization but also questions of development, such as how newborn animals distinguish objects at a distance. He insisted that, as products of the brain, the mental phenomena of instinct and intelligence were just as susceptible to experimentation as was the functioning of any other organ. Accordingly, he set out to study the mental capacities of a variety of animals.

Cuvier's first such investigation was of an animal not actually confined at the zoo. In 1810 he published an account of a young female orangutan he had observed for several months in the home of an attorney who was attempting to nurse the creature back to health for a naval officer friend (the officer had brought the animal to Paris as a gift for the Empress Joséphine). What impressed Cuvier most about the orangutan was her circumspection, which he believed was necessary because "nature has given the orangutan rather little means of defense." She was said to have exercised considerable caution when first on board ship, holding tight to lines and other attachments as the vessel rolled. Once in Paris, she acted in ways Cuvier interpreted as signs of intelligent self-defense. "Often she found herself tired out by the numerous visits she received; then she hid herself completely under her blanket and only came out from under it after the curious had left; she never did that when she was surrounded by people she knew."

Cuvier also credited the orangutan with the capacity to generalize. He observed, for instance, that if she wanted to stay in a tree, she would shake the branches when someone tried to climb up and get her. Cuvier concluded that prior experience had taught her that the fear of falling would discourage her pursuer. Likewise, when she moved a chair in order to reach and open a lock and when she took care to cover herself at night, Cuvier saw this as her exhibiting, in addi-

tion to the ability to generalize, "the awareness of a future need."

As impressed as he was by the orangutan's abilities, Cuvier took care to state that the ape was surely "not a man." This was not a matter, he insisted, of any differences between the sense organs of orangutans and humans. The orangutan, he said, had "senses as numerous and at least as delicate as ours." Cuvier maintained that the mental faculties distinguishing the higher animals from one another depend on brainpower and, likewise, that the brain is "the principal cause of the intellectual qualities that distinguish us from the animals."

In 1838 Frédéric Cuvier died suddenly, leaving his observations on animal behavior scattered and the synthesis he hoped to write unfinished.

HISTOIRE NATURELLE DES MAMMIFÈRES. MEGAN CARLOUGH; AMNH.

One of the rare and treasured births in the early days of the Paris zoo was that of a female white-fronted lemur.

At the zoo, Cuvier also studied the intelligence of seals. He was struck both by how readily these animals could be trained and by the tenacity with which they clung to the habits they formed: "I was never able to make the animals I observed eat any other species of fish than that with which we first fed them. One never wanted to eat anything but herrings; another ate only sole. The first even preferred salted herrings to other fresh species; the second actually died of hunger because we were unable to feed him sole owing to the seasonal storms that temporarily suspended fishing."

To investigate the relative roles of instinct and intelligence in shaping animal behavior, Cuvier reared a number of beavers in isolation from others of their kind. He found that these solitary, untutored individuals still displayed an instinctive tendency to build when provided with willow branches, straw, and earth. Beaver dams, he decided, are not the result of projects the animals undertake intelligently but instead are merely "the fruits of an industry that is entirely mechanical."

Cuvier was also eager to compare animals that had been successfully domesticated with others that had not. One of his subjects was a male bison sent to Paris from the United States in 1819. Bison had been touted as excellent candidates for domestication in France—infinitely stronger than oxen as beasts of burden and, when hybridized with cows, great producers of milk. Cuvier succeeded in mating a cow with the menagerie's bison, but the ensuing pregnancy came to a disastrous end. The cow suffered for eight days before a forced delivery was attempted. The calf died in the operation; the cow died four days later. Cuvier tersely reported the results to the professors: "The infant resembled entirely a young bison; it has been stuffed."

Hating to see animals suffer, he never attempted such a mating again. He also decided that bison were unsuitable as farm animals: every time one turned one's back on the menagerie's bison, it attacked. This and other experiences with many species of animals led Cuvier to conclude that herbivores (especially adult males) are not by nature more gentle than carnivores and that domestication is possible only in species already instinctively disposed to sociability.

Georges Cuvier died unexpectedly in May 1832 from an illness diagnosed as acute myelitis, and his position as professor of comparative

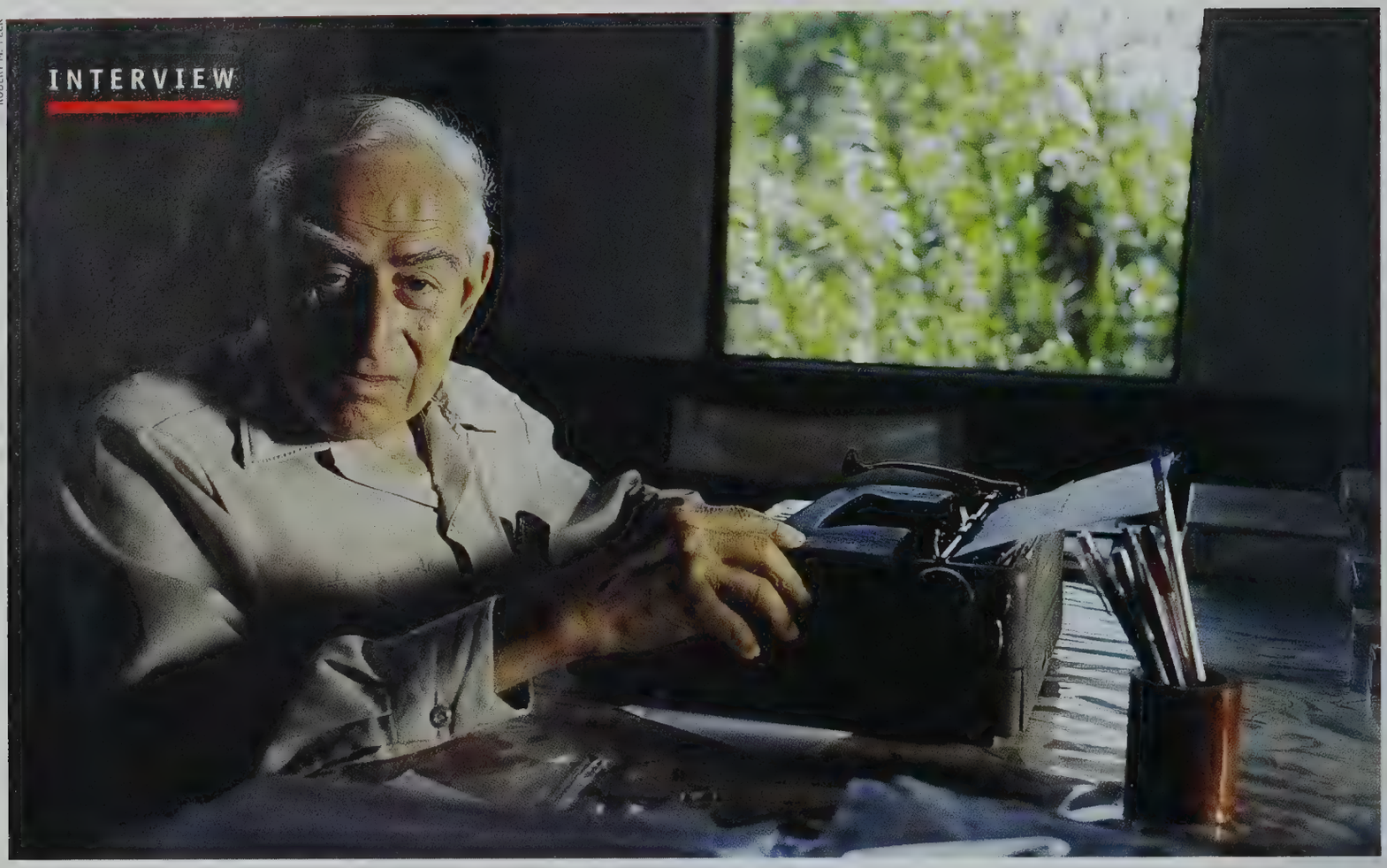
anatomy was filled in a matter of days, as was the museum's custom. Frédéric waited respectfully until the end of July to put forward his own case, asking for the creation of a new professorship devoted to the study of "living animals and their education." He offered the following justification for his proposal: "Since I have been in charge of the menagerie, all my researches, all my works, have been directed principally toward the knowledge of living animals, toward the means of observing them, of submitting them to planned experiments in order to understand the laws of their existence, as well as the nature of the modifications these laws can undergo." After five and a half years of institutional infighting, Frédéric Cuvier received his long-awaited chair at the museum in December 1837. Sadly, however, only eight months later, he suddenly became ill and died. His symptoms were much like those of the disease that had killed his brother. On his deathbed, Frédéric, accustomed to living in the shadow of his more famous sibling, requested that he be identified on his tombstone simply as "brother of Georges Cuvier."

In the early 1820s Frédéric Cuvier had expressed his intention to write a general work on the causes of animal actions. Such a work would have been invaluable, for no other naturalist in the first half of the nineteenth century studied mammalian behavior with the same care and breadth that he did. Unfortunately, at his death, his observations remained scattered and his synthesis unfinished. Frédéric Cuvier's pioneering efforts to establish a science of animal behavior failed to take hold.

As zoos were set up in other capitals and major urban centers—such as London (1827), Amsterdam (1838), and Berlin (1844), to name just a few—the menagerie in Paris ceased to be the world's finest collection of living animals. Though none of these others surpassed the Paris zoo of Frédéric Cuvier's day as a study site (and although the issue of whether it was better to study animals in the wild or in captivity remained unresolved), Cuvier was not the only nineteenth-century zoologist to take an interest in the behavior of zoo animals. In 1838, only a few weeks after Frédéric Cuvier's death, Charles Darwin visited the London zoo and, as he wrote in his notebook, "endeavoured to classify the expressions of monkeys." □

ZOOLOGICAL SOCIETY OF LONDON

Opening thirty-five years after the Paris zoo, the London zoo proved equally popular with members of the public, including Charles Darwin.



ROBERT M. PECK

A Conversation With Alexander F. Skutch

A naturalist who has revealed the private lives of Neotropical birds

For almost three-quarters of a century, naturalist Alexander F. Skutch has studied the wildlife of Central America, particularly its birds. Of his eighteen books, the most recent is Harmony and Conflict in the Living World, *illustrated by Dana Gardner and published last year by the University of Oklahoma Press. His autobiographical accounts* A Naturalist in Costa Rica *(1971) and* A Naturalist on a Tropical Farm *(1980) have become classics. Now ninety-six, the Maryland-born Skutch lives at Los Cosingos, a 178-acre farm he bought in southern Costa Rica more than sixty years ago. Skutch, who prefers the company of wild things to the hubbub of the outside world, has not owned an automobile since his college days and lives without benefit of electricity or a telephone in the house he built himself. Until the 1970s, when a gravity-fed water line was brought to the house, Skutch relied on a nearby stream for drinking, washing, and bathing. He grows corn, bananas, yuca, and other crops and prides himself on being almost entirely self-sufficient. A lifelong vegetarian, Skutch feels strongly about treading lightly on the Earth. On a warm afternoon at the start of last year's rainy season, naturalist and historian Robert McCracken Peck, a Fellow of the Academy of Natural Sciences in Philadelphia, visited with Skutch, who put aside work on his latest manuscript (a treatise advocating "biocompatibility," or peaceful coexistence between humans and the rest of Earth's species) to reflect on his long and remarkably productive life.*

RMP: *When you first came to the Tropics, it was as a botanist, not as an ornithologist. What inspired you to switch your primary focus from plants to birds?*

AFS: My first visit to the Tropics was to Jamaica, where Duncan S. Johnson, my professor of botany at Johns Hopkins University, led a party of his graduate students and friends. To earn my steamship passage and return, I stayed and worked on a banana plantation owned by the United Fruit Company. There I made a study of the banana leaf, which became the foundation of the doctoral dissertation that earned me my Ph.D. in 1928. Later that year I went to the fruit company's small research station in western Panama to continue my studies of the banana

plant. For six months I worked in a small laboratory amid the bananas. In front of the window where I sat at my microscope, examining bits of banana leaves, a rufous-tailed hummingbird built her nest and raised her brood. I found this, and the many other birds that nested in the garden, so fascinating that I decided to learn more about tropical American birds. After my return to the United States, I delved into the literature and found that nearly every species had been collected, named, and minutely described but that very little was known about their habits. I concluded that I could do nothing more important and satisfying than to learn the intimate details of their lives.

RMP: *You have written that you ultimately chose to settle in Costa Rica because of its rich Neotropical birdlife and because the country has been more peaceful than its neighbors. What are the biggest changes you've noticed during your tenure in the country?*
AFS: The soaring population of Costa Rica, from less than a million when I arrived in 1935 to more than three and a half million today, has caused great changes. I was attracted to the southern Pacific quarter of Costa Rica by the large expanses of unspoiled forest, nearly all of which have since been destroyed. Fortunately, a very generous amount of forest countrywide is now being protected in national parks and refuges.

RMP: *Much of your professional life has focused on birds. What do you consider your most important contribution to ornithology?*
AFS: Writing about the life histories of many tropical birds, whose nesting and other habits were previously little known or completely unknown—and, in particular, calling attention to the prevalence of cooperative breeding (helpers at the nest) in birds. My first paper on the subject, published in the *Auk* in 1935, was about three species of cooperative breeders that I watched in Guatemala. My second paper on this, "Helpers Among Birds," which appeared in the *Condor* in 1961, more effectively called attention to this behavior.

RMP: *Who are the naturalist-writers you most admire?*
AFS: Of all the writers I have read, my attitude toward nature has been closest to that of Plutarch, who believed in the integrity of nonhuman creatures. Charles Darwin, Alfred Russel Wallace, William H. Hudson, Henry Walter Bates, Thomas Belt, Frank Chapman, and David and Barbara Snow—they all write well and report fresh observations and/or interpretations.

RMP: *What advice would you give to a young person considering a career in ornithology today?*
AFS: Learn a little Spanish or Portuguese and go to tropical America to study the habits of little-known Neotropical birds; treat the birds that you watch with the respect due to sensitive, feeling creatures; and publish your findings without the needless excess of probability estimates that are making today's ornithological papers hardly readable. Ornithology should not be dominated by mathematics, which is more appropriate for physics and astronomy.

RMP: *If you had an opportunity to start over again, would you focus on something else?*
AFS: I would choose the same career, certainly in tropical America and probably in Costa Rica, which has a rich avifauna and on the whole has treated me well. I would study the migratory birds that winter in the Tropics. Although many of these birds have been thoroughly studied in North America and Europe—their "summering grounds"—their lives in the Tropics are still very poorly understood.

EXCERPT

Color attracts color, especially in the Tropics. To the bright red blossoms of the flame-of-the-forest trees were added the scarlet, orange, yellow, glittering green, deep blue, and turquoise of the tanagers, orioles, honeycreepers, hummingbirds, and other feathered visitors that probed the trumpet flowers for insects and nectar or hunted through the foliage for caterpillars and spiders. What a brilliant display the birds and flowers made in the bright beams of the rising sun!

ROBERT M. PECK

Sometimes, when I stood watching the birds in one of these trees while the sun still hung low above the wooded ridge across the river, a flock of great scarlet macaws came from the east, as though riding down the level sunbeams. Two by two they flew, with steady, laborious wing beats, their long tails streaming like slender pennants behind their heavy bodies, their scarlet underplumage glowing vividly where touched by the horizontal rays. As the macaws passed overhead, their raucous shouts made them as objectionable to the ear as they were pleasing to the eye. Often these flamboyant birds flew directly above the crown of a flame-of-the-forest tree, in a gorgeous display such as one expects of tropical nature.

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MUSEUM EVENTS

FEBRUARY 8
Lecture: "The Ecology of Zebra Sociality and Conservation: Different Stripes for Different Types" ("Earthwatch at the Museum" series). Daniel Rubenstein, of Princeton University. 7:00 P.M., Kaufmann Theater.

FEBRUARY 13
Isaac Asimov Memorial Panel Debate: "The Theory of Everything." Inaugural of an annual forum of celebrated scientists discussing questions on the forefront of scientific discovery. This year's speakers are physicists Brian Greene, Columbia University; Lisa Randall, MIT; S. James Gates, University of Maryland; Lawrence Krauss, Case Western Reserve University; and 1979 Nobel laureate Sheldon Glashow, Harvard University. 7:30 P.M., IMAX Theater.

FEBRUARY 17
Lecture: "The 'Juicy' Earth" ("Water: Earth, Air, and Fire" series). Rosamond Kinzler, of AMNH's National Center for Science Literacy, Education, and Technology, speaks on the role of water in the formation of continents and in plate tectonics. 1:30 P.M., Linder Theater.

FEBRUARY 19
Online expedition: MayaQuest 2001, at www.classroom.com. Students can join a four-week course exploring ancient Mayan civilization and contemporary Mayan cultures. Participants set the team's weekly course and, together with scientists, solve ethical dilemmas and investigate actual scientific, cultural, and historical mysteries. Sponsored by Classroom Connect in partnership with AMNH.

FEBRUARY 24
Identification Day: AMNH staff provide information on the history and classification of all materials presented. No appraisals. 1:00–4:30 P.M., Birds of the World Hall (second floor).

FEBRUARY 26
Lecture: "Turn Left at Orion: One Hundred Night Sky Objects" ("Distinguished Authors in Astronomy" series). Tour of the night sky—and talk on some of its mysteries—by Guy Consolmagno, an astronomer at the Vatican Observatory, and Dan Davis, a geoscientist at SUNY Stonybrook. 7:30 P.M., Space Theater, Hayden Planetarium.

DURING FEBRUARY
"African Diaspora Celebration: Fusions, Faces, and Footprints." During Black History Month, AMNH presents free weekend programs on race and identity, the influence of jazz, and African American dance traditions. 1:00–5:00 P.M., Leonhardt People Center. For information, call (212) 769-5315.

Online newsletter for Center for Biodiversity and Conservation: research.amnh.org/biodiversity/webletter.html.

Planetarium courses: "How to Choose a Telescope," "The Science of the Rose Center," and many others. For a complete schedule, call (212) 769-5100 or visit www.amnh.org/education/.

Films at the IMAX Theater: *Dolphins* (marine mammals in the wild, with a soundtrack by Sting) and *Ocean Oasis* (the biodiversity of the Baja California peninsula).

COMPUTER SIMULATION BY MOLLY LENORE; AMNH

At the Museum's new Weston Pavilion entrance on Columbus Avenue, scheduled to open at the end of January, visitors can see a monumental steel sculpture based on an instrument called an armillary sphere. Historically, this device enabled astronomers to locate planets and stars at a given time with respect to Earth. The sculpture features our galaxy, sectioned into octants—a symbolic guide to future space navigation. The sphere was conceived by the Museum's Department of Exhibition under the direction of its vice president David Harvey.

The American Museum of Natural History is located at Central Park West and 79th Street in New York City. For listings of events, exhibitions, and hours, call (212) 769-5100 or visit the Museum's Web site at www.amnh.org. Space Show tickets, retail products, and Museum memberships are also available online.

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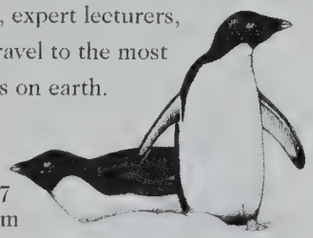

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REVIEW

Long Live the !Kung

A touchstone for students of humanity's past, hunter-gatherer societies forge their own destinies. *By Meredith F. Small*

Nisa in 1971

When Marjorie Shostak died in 1996, anthropology lost two compelling voices—Shostak, a keen observer and passionate writer, and Nisa, whose words and personality fill Shostak's narratives about the lives of !Kung women. In 1969 Shostak joined a team of Harvard University anthropologists who had begun a long-term study of the !Kung San (Bushmen) six years earlier. She spent twenty months interviewing !Kung women in the Dobe area of northwestern Botswana, in the northern Kalahari Desert. Fifty-year-old Nisa, whose stories seemed to Shostak "larger and more important than the details they comprised," stood out.

First published in 1981, *Nisa: The Life and Words of a !Kung Woman* is not just an ethnographic account of a people but a singular tale told in Nisa's own words. The book became a classic, selling over 200,000 copies. I doubt there is a single anthropology or women's studies student in the past two decades who hasn't been assigned this book. Now *Return to Nisa* chronicles the story of Shostak's month-long visit to the !Kung in 1989. No standard anthropology text, this is a personal memoir, haunted by Shostak's battle with breast cancer.

"My future had been cast into deep, threatening shadow; the present turned in on itself as my daily experience acquired a brutal, slashing edge," she writes, referring to her cancer diagnosis and mastectomy in 1988. Although she wanted to see Nisa again, she had to consider the consequences of an extended separation from her husband and children (including a two-year-old who had been weaned early, after Shostak's cancer was diagnosed). Yet Africa called in a way familiar only to those who have spent time in the field: "The decision to go had preceded the practical, starting with a need, the need to return: to see, to taste, to smell, to experience again, perhaps even to heal."

Shostak sets out for Dobe once more, but the romantic vision of a quest soon evaporates. This time, Nisa's people are more concerned with their own affairs than with talking to Shostak, and Shostak is exhausted by illness and travel. Her relationship with Nisa is full of ambiguity. "Nisa seems to have so little compassion, at least for me," Shostak writes. "She likes me because I have rewarded her for our work. She has no idea of what I feel. I don't even think she likes me in any real sense. I sometimes wonder if I even like her." On this trip, Shostak is drawn to anything that might pull the evil from her body. She hires the healer Kxoma to perform a ceremonial trance dance and hires Nisa (also a healer) to perform a drum dance. For Shostak these are spiritual moments; for the !Kung they are performances, and everyone wants to be paid. Here we have fieldwork, warts and all.

Return to Nisa offers no neat package of connection and redemption, but Shostak does tell a compelling tale of her need to revisit a place and a people who represented a defining period in her life. She also looks at the pressures that are moving the !Kung away from hunting and gathering: the border war between Botswana and Namibia that slices through their ancestral land and separates families; the scarcity of game; the acquisition of cows, which requires a more settled life; and interruptions in the transmission of skills from the elder to the younger generations.

Shostak finds that the !Kung re-

Nisa: The Life and Words of a !Kung Woman, *by Marjorie Shostak (Harvard University Press, reprint, 2000; $16.95)*

Return to Nisa, *by Marjorie Shostak (Harvard University Press, 2000; $24.95)*

The Cambridge Encyclopedia of Hunters and Gatherers, *edited by Richard B. Lee and Richard Daly (Cambridge University Press, 1999; $125)*

spond to these changes with a certain resilience—a characteristic not only of the !Kung but of other peoples like them, according to *The Cambridge Encyclopedia of Hunters and Gatherers.* In what has proved to be the most successful pattern of adaptation in human history, people have hunted and gathered for millions of years, turning to sedentary agriculture only 12,000 years ago and to industrialization (with its disconnection from the land) a mere 200 years ago. Indeed, the globe is dotted with groups that still partly rely on foraging.

The encyclopedia's eighty-eight contributors present the history, ecological setting, economy, political organization, social organization, spirituality, and current status of more than fifty societies from seven geographical areas. Described as generally egalitarian, cooperative, and on the move, these people readily split into small groups or temporarily gather together as circumstances demand. They still forage in forests, across savannas, and on ice packs but also utilize the goods and services of sedentary neighbors, incorporating modern food and tools into the hunting and gathering life.

MARJORIE SHOSTAK; ANTHRO-PHOTO FILE

Marjorie Shostak and Nisa in 1989

All, of course, have been affected by the pressures of colonization, the loss of land, and political strife. Remarkably, many groups have recently banded together to preserve their way of life. "Far from being simply the cast-offs of creation or victims of history, the foraging peoples have become political actors in their own right, mounting land claims cases, participating in the environmental movement, and lobbying for their rights with governments and the UN," write editors Richard B. Lee, a University of Toronto anthropologist who was part of the first team to study the !Kung, and Richard Daly, an anthropologist who works on aboriginal rights cases in British Columbia. Such a political voice might allow these groups to survive in the modern, electronically interconnected world—and to survive in the way *they* choose.

Historically, Westerners have either vilified hunters and gatherers as savages or they have worshiped them as living testimonies of ancient and more "natural" modes of existence. Anthropologists have always been interested in them as windows to our past. But as *Nisa, Return to Nisa,* and *The Cambridge Encyclopedia of Hunters and Gatherers* demonstrate, these people are not museum specimens but members of dynamic societies, both connected to the past and moving forward.

Meredith F. Small is a writer and a professor of anthropology at Cornell University.

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Glowing Dinos

By Robert Anderson

Organisms that produce their own light are predominantly a marine phenomenon. Terrestrial bioluminescence is a rarity limited to a few insects (such as fireflies) and to certain earthworms and fungi. The reason for this disparity is simple, according to the Bioluminescence Web Page (lifesci.ucsb.edu/~biolum/), maintained at the University of California, Santa Barbara: the glow that animals generate themselves is the only source of light in the deep ocean, our planet's largest habitat.

Biologists can exchange new research findings at this site, but there's also plenty for the layperson. It explains in simple terms how organisms mix molecules called luciferins with luciferases to produce light. We are cautioned against confusing bioluminescence with fluorescence and phosphorescence. A gallery of glowing marine creatures reveals the beauty and wide range of species that illuminate the oceans. Certain squids adjust the color of their luminescence to match moonlight or sunlight; like fireflies, certain crustaceans send coded light messages at mating time; and the black dragonfish, a deep-sea dweller, has evolved its own "night vision" equipment. Most creatures emit a bluish green glow, but this dragonfish can shine red light on its prey that is visible to its eyes alone.

STEVEN HADDOCK

Bioluminescent comb jelly

The highlight of the site, however, has to be the section on how to grow your own dinos, or dinoflagellates. (On the main page, click on "Organisms" and then on "Dinoflagellates.") These single-celled organisms, which swim free as plankton, are by far the most common bioluminescent creatures on the planet. The section also suggests a number of experiments you can perform with your jar of blue-flashing dinos.

Robert Anderson is a freelance science writer living in Los Angeles.

PHOTOGRAPHY

Crossing Over: Where Art and Science Meet, *by Stephen Jay Gould and Rosamond Wolff Purcell (Three Rivers Press, 2000, $27.50)*

BOOKSHELF

Nature Out of Place: Biological Invasions in the Global Age, *by Jason Van Driesche and Roy Van Driesche (Island Press, 2000; $29.95)*

Tinkering With Eden: A Natural History of Exotics in America, *by Kim Todd (W. W. Norton, 2001; $27.95)*

Invasive Species in a Changing World, *edited by Harold A. Mooney and Richard J. Hobbs (Island Press, 2000; $55)*

Virtually no place on Earth remains isolated from migrant faunal, floral, or microbial species. Three books zero in on the ecological problems, dangers, costs, and even benefits associated with such bioinvasions.

The Living Wild, *by Art Wolfe; edited by Michelle A. Gilders (Wildlands Press, 2000; $55)*

Wildlife photographer Wolfe's striking portraits of 140 species of animals and their habitats are accompanied by essays written by scientists and conservationists William Conway, Richard Dawkins, Jane Goodall, John C. Sawhill, and George B. Schaller.

Reaping the Wind: How Mechanical Wizards, Visionaries, and Profiteers Helped Shape Our Energy Future, *by Peter Asmus (Island Press, 2000; $24.95)*

"The winds blowing on just 6 percent of the windiest land sites in the United States (excluding Hawaii and Alaska) could supply one and one-half times the entire nation's electricity needs," writes journalist Asmus in his account of the stormy history of attempts to create U.S. markets for wind power.

Beneath Our Feet: The Rocks of Planet Earth, *by Ron Vernon (Cambridge University Press, 2000; $29.95)*

The surface of our planet is a mass of vividly patterned inorganic chemical compounds that are aggregated into solids with names such as olivine, gabbro, basalt, and breccia. Here is a guidebook to that glittering ground.

No Man's Garden: Thoreau and a New Vision for Civilization and Nature, *by Daniel B. Botkin (Island Press, 2000; $24.95)*

Ecologist Botkin meditates on how Thoreau's approach to knowledge can help us not only make thoughtful contact with the natural world but also deal with revolutionary developments in biology and computer science.

Half a Brain Is Enough: The Story of Nico, *by Antonio M. Battro (Cambridge University Press, 2001; $19.95)*

A neuroscientist tells the story of the successful "sculpting" of three-year-old Nico's brain following radical surgery to cure severe epilepsy.

The books mentioned are usually available in the Museum Shop or through the Museum's Web site, www.amnh.org.

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UNIVERSE

The Beginning of Science

Reports that physicists are nearing the final frontier of knowledge have been greatly exaggerated.

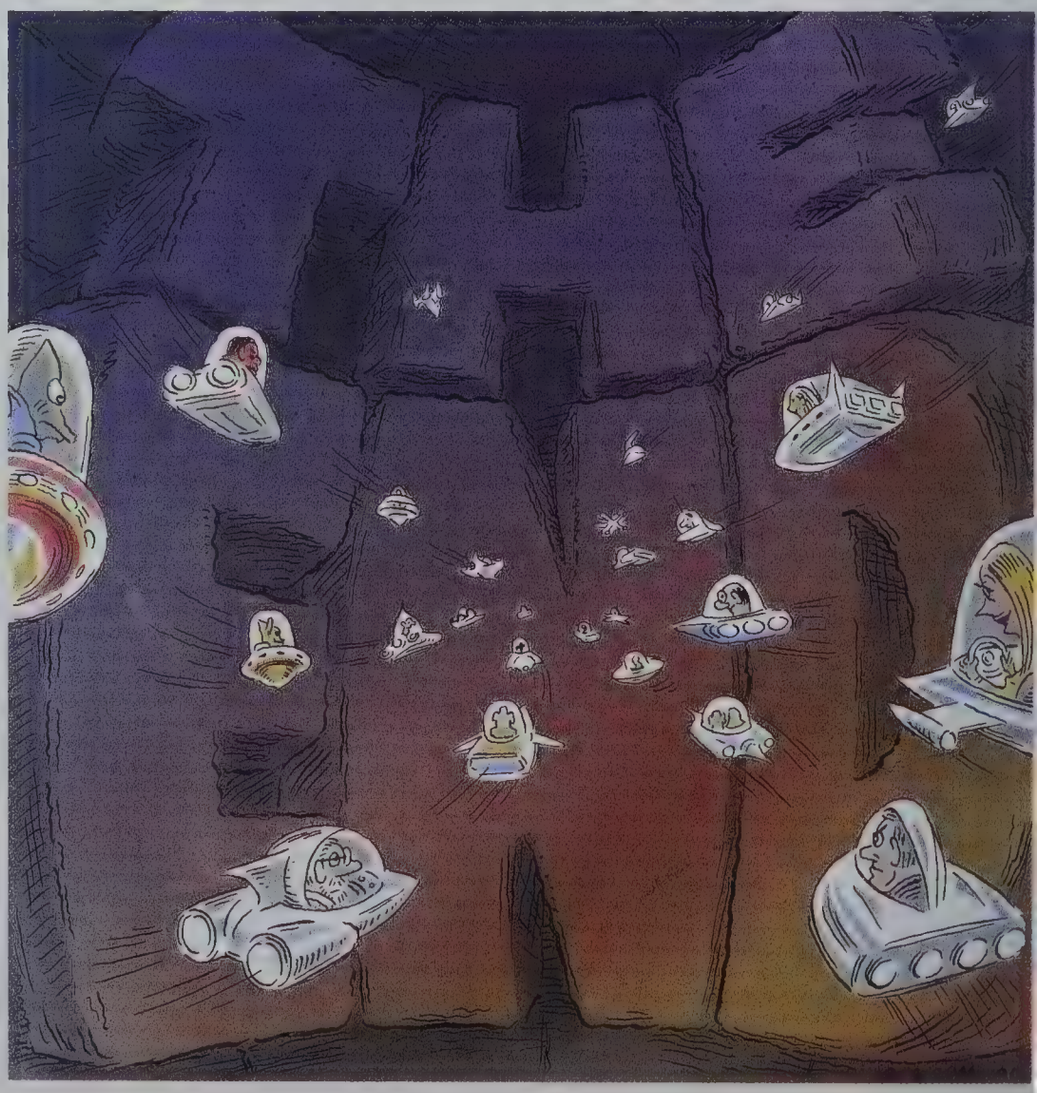
By Neil de Grasse Tyson

The success of known physical laws at explaining the world around us has consistently bred some confident and even cocky attitudes toward the state of human knowledge. Even Nobel laureates and other esteemed scientists have embarrassed themselves by proclaiming that the end of science was near.

The distinguished astronomer Simon Newcomb, one of the founders of the American Astronomical Society, noted in 1888, "We are probably nearing the limit of all we can know about astronomy." Another famous end-of-science prediction was delivered in 1894, in a speech given by the future Nobelist Albert A. Michelson at the dedication of the University of Chicago's Ryerson Physical Laboratory:

> *The more important fundamental laws and facts of physical science have all been discovered, and these are now so firmly established that the possibility of their ever being supplanted in consequence of new discoveries is exceedingly remote. . . . Our future discoveries must be looked for in the sixth place of decimals.*

Even the great physicist William Thomson—aka Lord Kelvin, father of the branch of physics called thermodynamics—fell victim to his own confidence in 1900 with the claim "There is nothing new to be discovered in physics now. All that remains is more and more precise measurement." His comments were expressed at a time when the so-called luminiferous ether was still the presumed medium in which light traveled through space, and when the slight difference be-



tween the observed and the predicted paths of Mercury around the Sun was a real and unsolved problem. But a century ago such details were considered minor, requiring for their resolution perhaps only slight adjustments to recognized physical laws. Indeed, Lord Kelvin referred to problems such as these as "small clouds on the horizon."

In a 1924 lecture, the physicist Max Planck reflected on advice given to him as a student in 1874:

> *When I began my physical studies and sought advice from my venerable teacher Philipp von Jolly . . . he portrayed to me physics as a highly developed, almost fully matured science. . . . Possibly in one or another nook there would perhaps be a dust particle or a small bubble to be examined and classified, but the system as a whole stood there fairly secured, and theoretical physics approached visibly that degree of perfection which, for example, geometry has had already for centuries.*

Planck, who sowed the first seeds of the quantum revolution, initially had no reason to doubt his teacher's views. But in 1900, when the classical understanding of how matter radiates energy could not be reconciled with experimental evidence, Planck became a reluctant revolutionary by suggesting the existence of the quantum, an indivisible unit of energy. His suggestion heralded a new era of physics: the next thirty years would see the formulation of the theories of relativity and quantum mechanics and the recognition that we live in an expanding universe.

With so many of his predecessors having proved myopic, you'd think that the brilliant and prolific physicist Richard Feynman would have known better. But in his 1965 book *The Character of Physical Law,* he declares,

> *We are very lucky to be living in an age in which we are still making discoveries. . . . The age in which we live is the age in which we are discovering the fundamental laws of nature, and that day will never come again. It is very exciting, it is marvelous, but this excitement will have to go.*

I claim no special knowledge of when and where the end of science might come or whether an end exists at all. What I do know is that our species is dumber than we normally admit to ourselves. This limitation of our mental faculties—but not necessarily of science itself—makes clear to me that we have only just begun to figure out the universe.

Let's assume that human beings are the smartest species now living on Earth. Let's further assume, for the sake of discussion, that our capacity to do abstract mathematics makes us the only smart species ever to have lived.

What are the chances that this first and only smart species in the history of life on Earth has enough smarts to understand all there is to know about the universe? Chimpanzees are an evolutionary hair's-width from us, yet I think we can agree that no amount of tutelage will ever leave a chimp fluent in trigonometry. Now imagine a species on Earth, or anywhere else, that is as smart compared with humans as humans are compared with chimps. How much of the universe might its average (let alone its cleverest) members figure out?

Tic-tac-toe fans know that the game's rules are simple enough to allow you to win or tie every time—if you know which opening moves to make. But young children play the game feeling that the outcome is remote and unknowable. The rules of engagement for chess are also clear and simple, but the challenge of predicting your opponent's upcoming sequence of moves grows exponentially by midgame. With this level of complexity,

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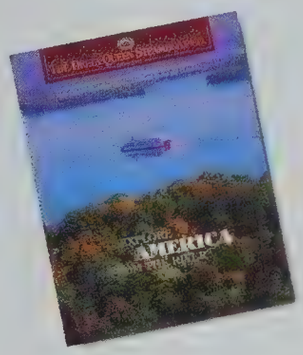

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most smart and talented adults find chess quite challenging and play it as though the end were a mystery. So, is the universe to us a game of tic-tac-toe or a game of chess?

Let's consider Isaac Newton, who leads my list of the smartest people who ever lived. (I am not alone here. An inscription on a bust of Newton at Trinity College in Cambridge, England, proclaims *"Qui genus humanum ingenio superavit,"* which loosely translates from Latin as "Of all humans, there is no greater intellect.") How did Newton regard his own brilliance?

> *I do not know what I appear to the world; but to myself I seem to have been only like a boy playing on a seashore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay undiscovered before me.*

The game that is our universe has revealed some of its rules, but much of the cosmos still behaves mysteriously—perhaps abiding by regulations not yet deduced or perhaps awaiting a clever application of the laws we already know.

The distinction between the knowledge of objects and phenomena and the knowledge of the laws that control them is central to any perception that science might be coming to an end. The discovery of life on the planet Mars or beneath the floating ice sheets of Jupiter's moon Europa would be the greatest news story yet. You can bet, however, that the physics and chemistry of molecules found there would be the same as the physics and chemistry of molecules here on Earth. No new laws necessary.

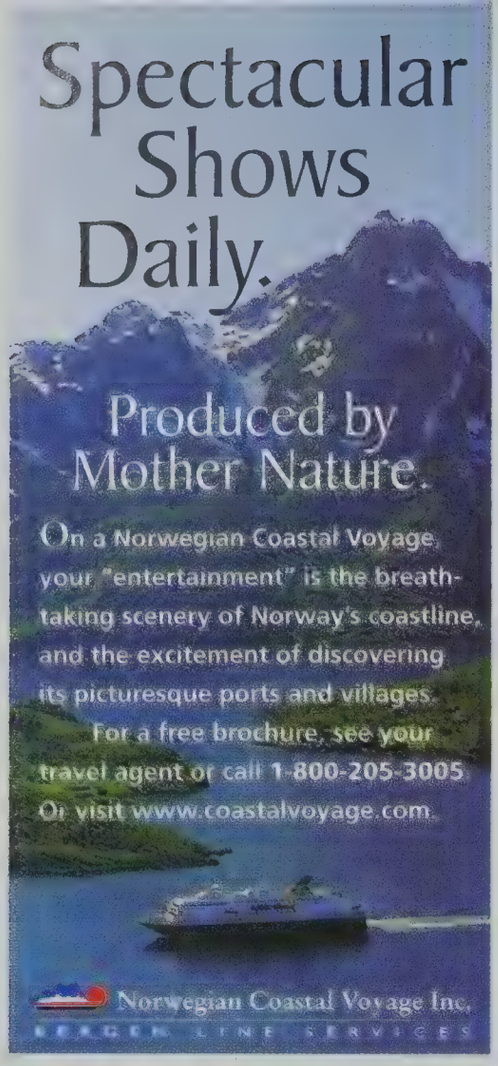
But let's peek at the underbelly of modern astrophysics and expose our contemporary ignorance by pointing to a few unsolved problems—the solutions to which, for all we know, await the discovery of entirely new branches of physics.

Newton's laws of motion and gravity looked good for 200 years, until they needed to be modified by Einstein's theories of motion and gravity—the relativity theories. Relativity now reigns supreme. Quantum mechanics, the description of the atomic and nuclear universe, also reigns supreme—except that in its present form, it cannot be reconciled with Einstein's theory of gravity. Both theories predict different phenomena for the domain in which they overlap.

Something's got to give.

Either there's a part missing from Einstein's gravity that would enable it to accept the tenets of quantum mechanics, or there's a part missing from quantum mechanics that would enable it to accept Einstein's gravity. Or maybe there's a third option: a larger, inclusive theory that supplants them both. Indeed, string theory has been invented and called upon to do just that. It attempts to reduce all matter, all energy, and all their interactions to the existence of higher-dimensional vibrating strings of energy. String theory holds that different modes of vibration reveal themselves in our measly four dimensions of space and time as different particles and forces. Although string theory has had its adherents for more than twenty years, its claims continue to lie beyond our current capacity to verify by experiment. Skep-

Let's peek at the underbelly of modern astrophysics and expose our contemporary ignorance by pointing to a few unsolved problems.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ticism is rampant, but many scientists remain hopeful.

Let's continue to probe our ignorance. While our confidence in the big-bang description of the origin of the universe is very great, we can only speculate what lies beyond our cosmic horizon, 13 billion light years away. We can only guess what happened before the big bang or why there should have been a big bang in the first place.

Want some more ignorance?

We have computer models that can account for the formation of galaxies in the early universe. But those same models fail when we use them to account for today's large-scale cosmic structures. A coherent description of the formation and evolution of galaxies continues to elude us. We seem to be missing some important pieces of the puzzle.

We still don't know what kind of chemistry enabled inanimate matter to assemble into life as we know it. Is there some mechanism or law of chemical self-organization that escapes our awareness? We have nothing with which to compare our Earth-based biology, and thus we cannot evaluate what is essential and what is irrelevant to the formation of life.

Ever since Edwin Hubble's seminal work during the 1920s, we've been aware that the universe is expanding. But we've only just learned that the universe is also accelerating, due to some antigravity pressure we call dark energy. No known physical process can account for this pressure.

And at the end of the day, no matter how confident we are in our observations, our experiments, or our theories, we must acknowledge that 90 percent of the gravity in the cosmos comes from some unknown, mysterious source whose identity eludes every means we have ever devised to observe the universe. As far as we can tell, it's not made of ordinary stuff such as electrons, protons, and neutrons or of any form of matter or energy that interacts with them. We call this offending substance dark matter, and it remains the greatest enigma of modern astrophysics.

Does any of this sound like the end of science? Does any of this sound like we are on top of the situation? Does any of this sound like it's time to congratulate ourselves? To me it sounds like we're all stupid, helpless idiots, no different from our kissing cousins, the chimpanzees, trying to learn the Pythagorean theorem.

Maybe I'm being a little hard on *Homo sapiens*. Perhaps the question should not be how smart an individual of a species is but how smart our collective brainpower makes us. Among humans, discoveries made by some are routinely shared with others through conferences, journals, books, the broadcast media, and, of course, the Internet. While natural selection drives Darwinian evolution, the growth of human culture is largely Lamarckian: new generations of humans inherit the acquired discoveries of generations past, enabling cosmic insight to grow slowly, but without limit.

With our unique capacity to stockpile and communicate knowledge, we continually transcend our own intellectual limits. Each discovery of science adds a rung to a ladder of knowledge whose beginning is in plain view but whose end is not in sight—we are building the ladder as we go along. By any measure of the ladder's height, we are closer to the beginning of science than to its end.

Neil de Grasse Tyson, an astrophysicist, is the Frederick P. Rose Director of the Hayden Planetarium at the American Museum of Natural History and is also a visiting research scientist at Princeton University. His memoir, The Sky Is Not the Limit: Adventures of an Urban Astrophysicist, *was published last year by Doubleday.*

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THE NATURAL MOMENT

Sea Bear

Polar bears are seagoing hunters that roam vast areas of the Arctic, pursuing a movable feast of seals, narwhals, beluga whales, and walruses. Individuals may range over 116,000 square miles. As the pack ice breaks up during the summer months, many bears head for land, returning to the sea when it freezes again in October and November.

Although it evolved from land-dwelling brown bears only 300,000 years ago, the white bear is superbly adapted to life on the frozen sea. In winter, when the ice is solid, polar bears may hunt by locating holes in the ice at which sea mammals breathe. When they surface, seals and whales leave a scent in the air that polar bears can detect from a distance of several miles downwind. In spring, the seals' breeding season, mother seals and their pups take refuge in agloos—little snow lairs atop the sea ice. Bears pounce on these refuges, killing or stunning the pups and occasionally the adults.

This photograph was taken on the northern tip of Baffin Island, near a long crack in the sea ice where photographer Paul Nicklen and his Inuit guide had set up camp to wait out a storm. As he strolled along the crack about a mile from his base, Nicklen suddenly spotted the bear walking in the direction of the camp—perhaps drawn by the aroma of some seal meat that was stored there. After a few minutes, the animal slipped into the water to make a more stealthy approach to the larder. Nicklen raced ahead to the tent, grabbed his camera, and returned to the water's edge to wait for the bear to emerge. As it surfaced right in front of Nicklen, his guide became alarmed and ran over to drive off the animal. Unperturbed, Nicklen clicked away, enjoying a moment of quiet communion with the bear as it took in the situation, reconsidered its intentions, shook off some water, and submerged again.—*Richard Milner*

Photograph by **Paul Nicklen**

ENDPAPER

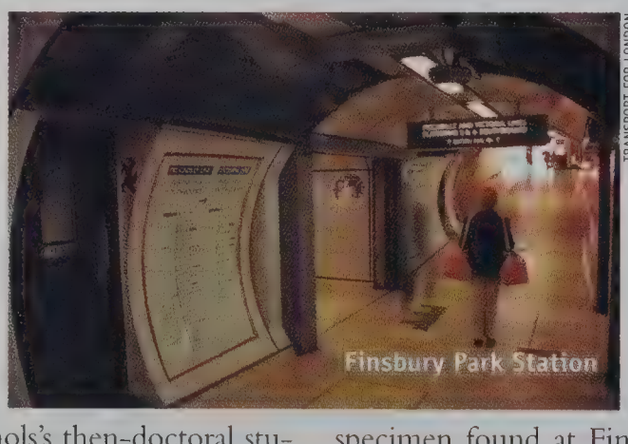
Insect From the Underground

By Alan Burdick

In *The Time Machine,* published in 1895, H. G. Wells envisions a human race divided. Aboveground, in a city of daylight, live the Eloi, while the bloodthirsty Morlocks toil in tunnels far below the ground. A century later, two real-life British geneticists have discovered an entomological analogue: a mosquito that is closely related to the one inhabiting the daytime streets of London but that lives exclusively in the tunnels of the London Underground. Unlike their upstairs brethren, which bite only birds, members of this subterranean race show a distinct affinity for human blood.

"They're quite voracious biters," says Richard Nichols, of Queen Mary and Westfield College at the University of London. "It's not that any one bite is all that bad, it's just that they all seem to want to get a bit of you."

The subterranean mosquitoes have been known for many decades; during World War II, Londoners who sought belowground shelter from the Blitz found themselves assaulted by the insects. Biologists named the attackers *Culex molestus,* presuming that they belonged to a species distinct from the aboveground *C. pipiens*. But until Nichols came along, the genetics had never been sorted out. He decided to unravel the mystery.



TRANSPORT FOR LONDON

The research legwork fell to Nichols's then-doctoral student Katherine Byrne, now a geneticist at the Institute of Zoology in London. After midnight, when the trains had shut down, Byrne followed maintenance workers into the subway's bustling underworld, where she soon discovered an ideal environment for mosquitoes. "The temperature is warm and virtually constant," Byrne says. "There's no rain, no snow: it's great for a year-round life cycle." The polluted pools of water, ranging from "pretty nasty" to "hideous," are prime mosquito-breeding sites. As with all mosquitoes, only the females—the egg layers—seek out blood, feeding on rats and pinstriped rat-racers alike. The males get by on what Byrne calls soluble nutrition: decaying rubbish, perspired salts, bits of hair, and "fluff," a thin haze of flaked-off human skin so pervasive in the Underground that specialized workers ("defluffers") must regularly clean it from the train's conduction rail.

By night, Byrne scavenged grim subterranean puddles for mosquito larvae. By day, she lurked aboveground in tony gardens and backyards, collecting specimens from water-filled buckets and beery vats of compost. Taking her larval captives—*C. pipiens* from upstairs and *C. molestus* from downstairs—she returned to the lab to raise them.

As adults, Byrne's subjects proved fascinating. Although the two varieties look identical, their habits differ sharply. *C. pipiens* hibernates in winter; *C. molestus* breeds year-round in the warm subway, but it cannot survive the cold. *C. pipiens* must swarm in the open before mating, whereas *C. molestus* thrives in confined spaces. When Byrne crossbred the two varieties, none produced viable eggs—suggesting that *C. molestus* is reproductively isolated, the traditional signature of a new species. (Given the great differences in their behavior, Byrne notes, *C. pipiens* and *C. molestus* probably rarely meet or mate "in the wild.")

Analyzing the DNA, Byrne and Nichols found that different colonies of the underground mosquitoes are more genetically similar to one another than to their aboveground brethren. A specimen of *C. molestus* discovered at Euston, on the Victoria line, is more closely related to a specimen found at Finsbury Park, miles away on the same line, than it is to a visibly identical specimen of *C. pipiens* captured just upstairs at Euston. In short, subterranean sites are being established by other underground mosquitoes, not by mosquitoes from above. How do the mosquitoes spread through the Underground? "We think that the trains act as pistons, pushing cushions of air"—and mosquitoes—"ahead of them," Nichols says.

And the insects continue to evolve. Byrne and Nichols have identified three genetically distinct subvarieties of *C. molestus,* each one unique to a different subway line: Victoria, Bakerloo, and Central. The other lines of the Underground probably harbor subvarieties of their own, Byrne adds, "and I'm sure they exist in sewers, though I've not been to look."

Alan Burdick is a writer/producer for AMNH's Science Bulletins.

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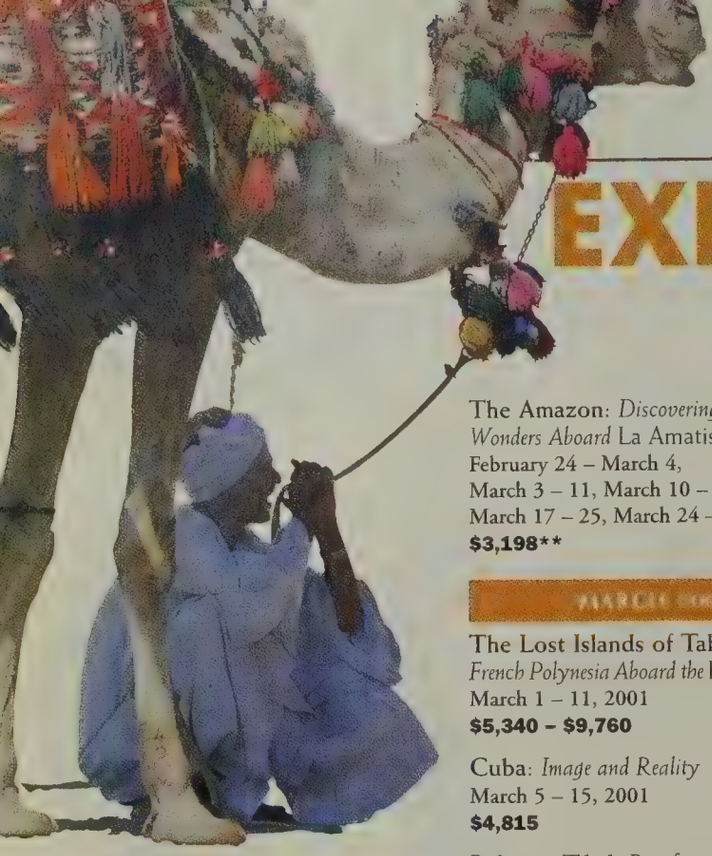

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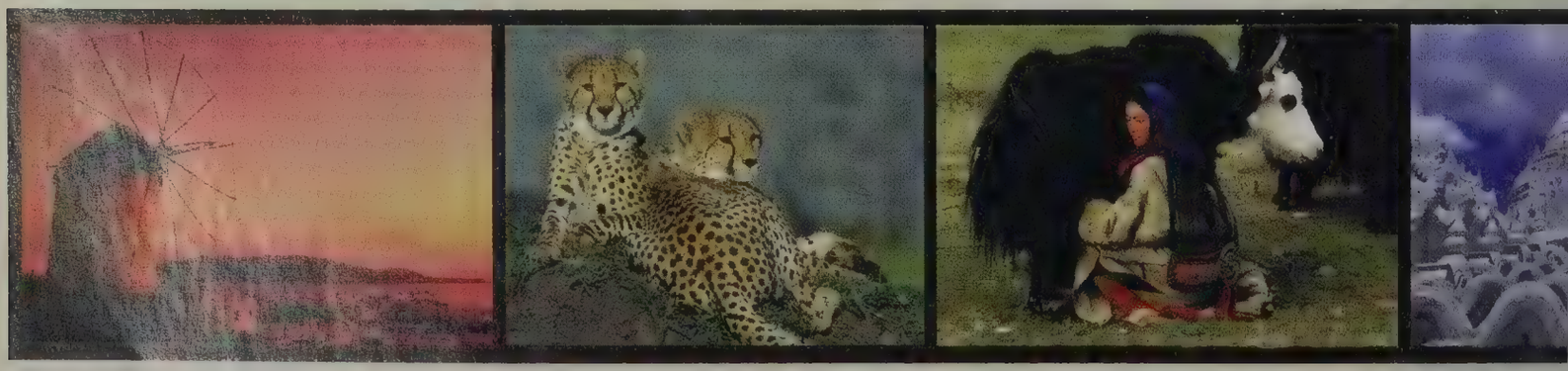

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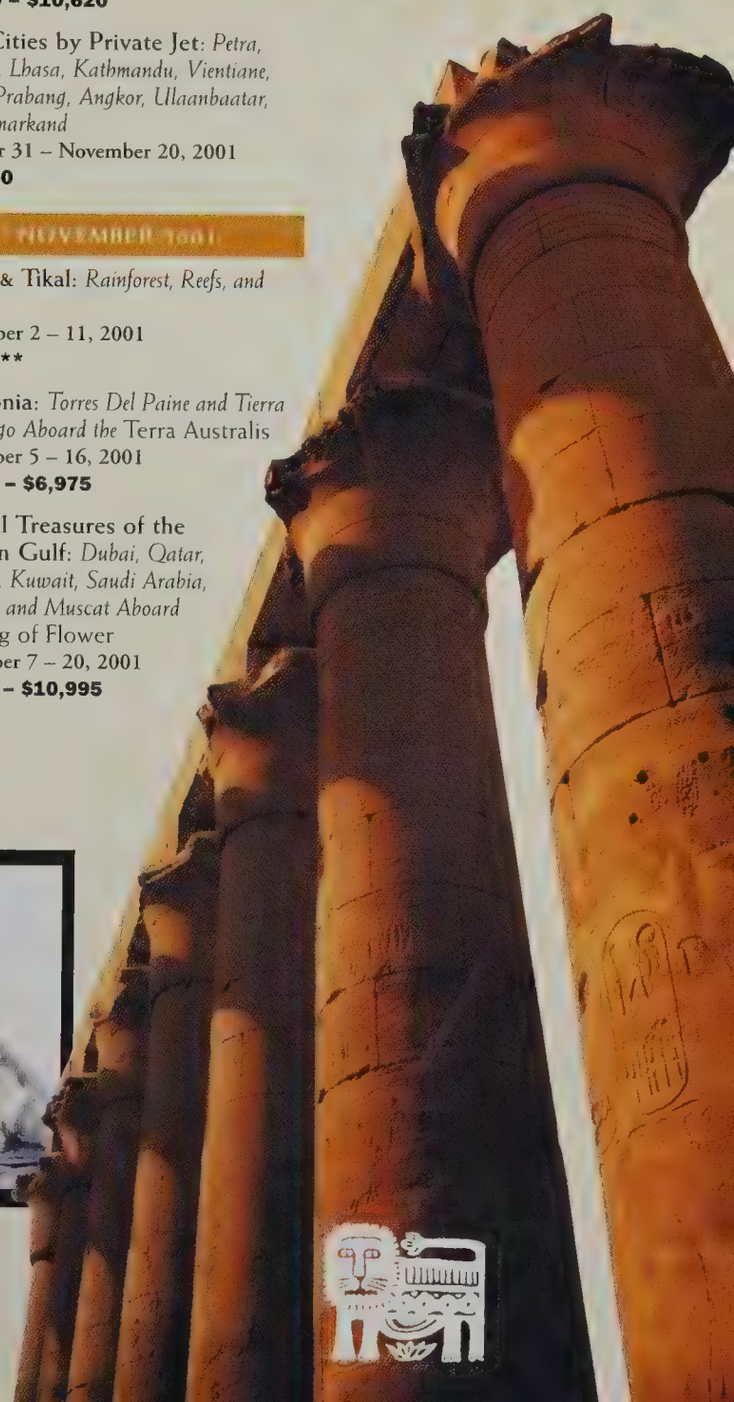

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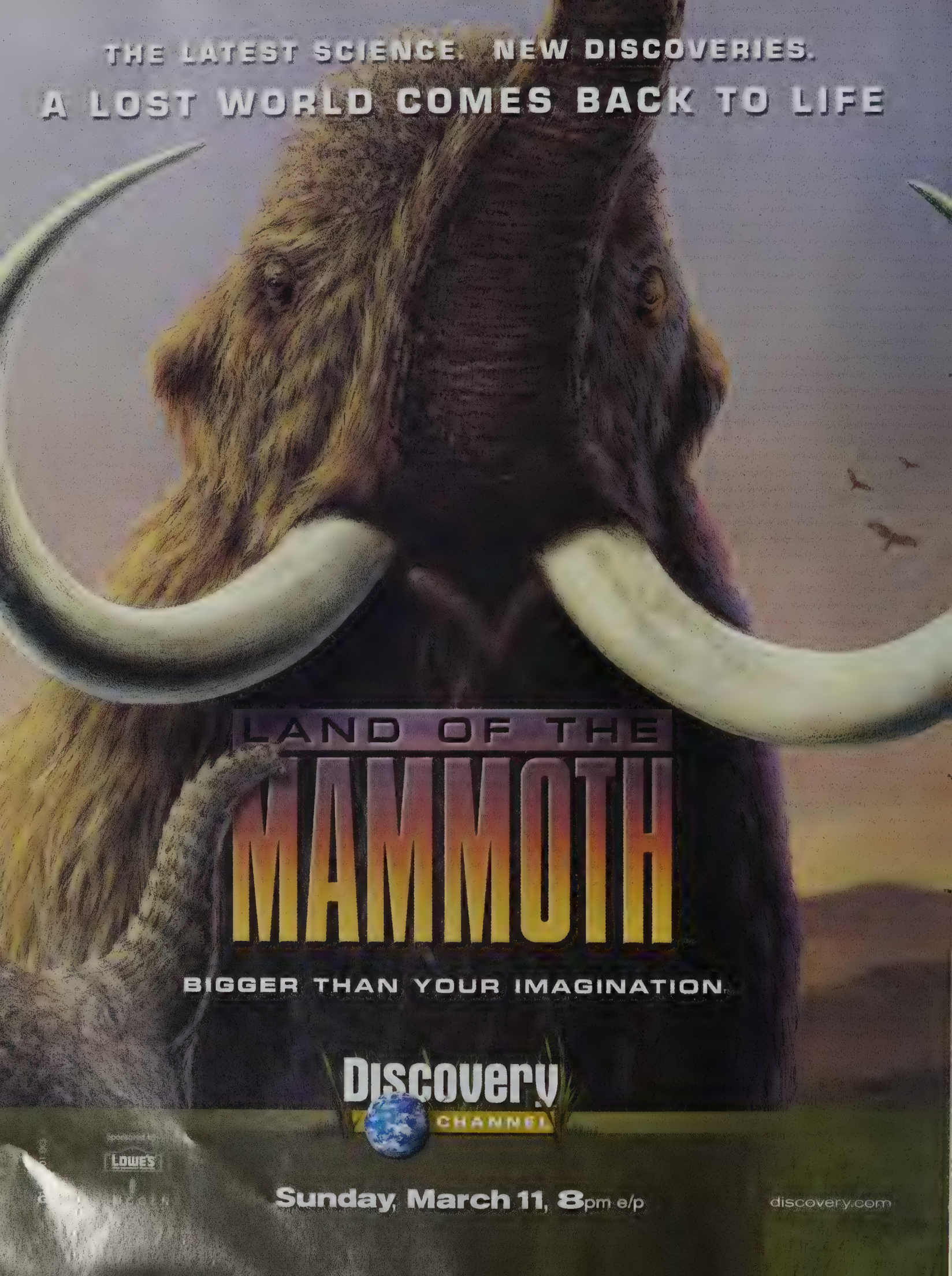
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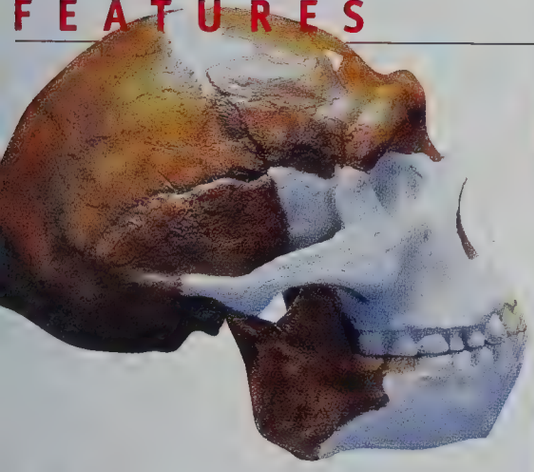

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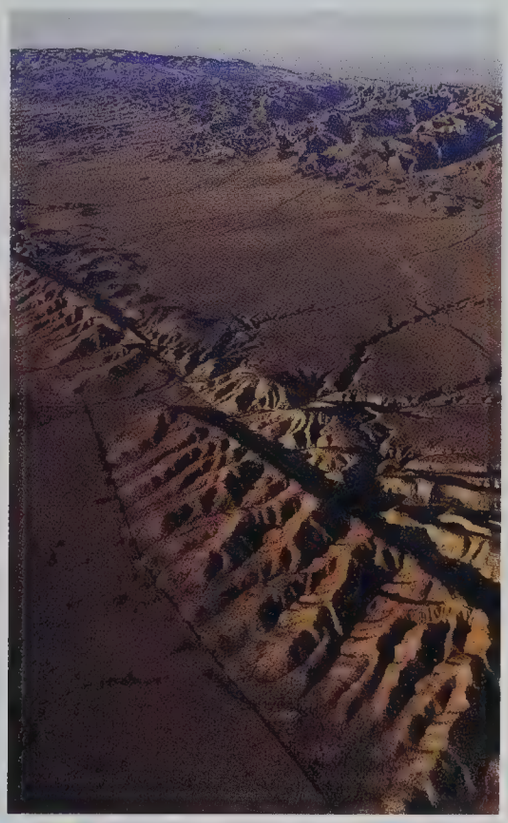

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A 1992 quake in the Mojave Desert upset some settled seismological notions.

BY SUSAN ELIZABETH HOUGH

COVER The seven-spotted ladybird beetle is found in Japan, a country with an insect-friendly culture.

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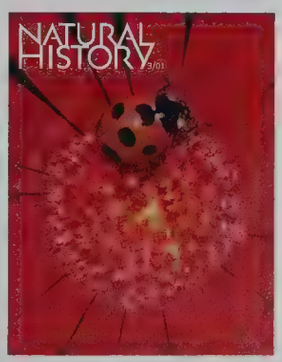
PHOTOGRAPH BY HIROSHI OGAWA; NATURE PRODUCTION



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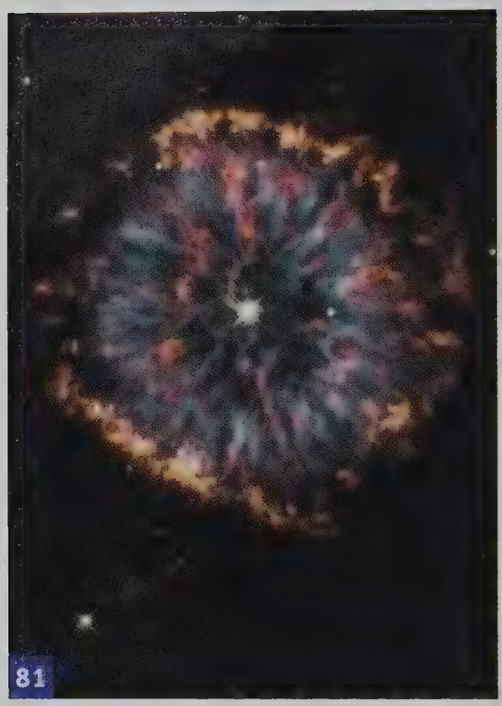

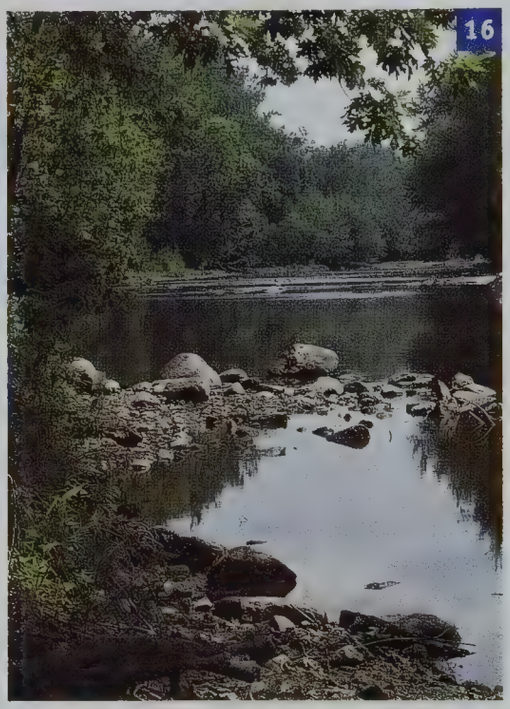

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UP FRONT

In Defense of Larvae

Larva. To a lot of people, the word signifies something half-formed, ugly, and likely to devour food stores, winter clothing, or green leaves. As a rule, we glorify the butterfly and dismiss the caterpillar. Exceptions may be made for tadpoles, which at least, like us, are vertebrates. Perhaps humans are inclined to this form of prejudice because we are direct developers, going from babyhood to reproductive maturity without changing much more than our bodily proportions. Yes, as embryos we have gills, and along the way to adulthood we pick up a few secondary sex characteristics, but we do not truly metamorphose. And when fictional humans undergo transformations in books and films, it's almost always bad news (think Gregor Samsa in Kafka's "Metamorphosis" or Vincent Price in *The Fly*).

PETER PARKS; IMAGE QUEST 3D

A scale worm larva

Fortunately for *Natural History*'s readers, some people appreciate metamorphosis and have made the study of larvae an important part of their life's work. One is evolutionary biologist Gregory A. Wray, who in this issue's special section, "A World Apart" (page 52), provides a corrective to direct-developers' chauvinism by pointing out that the larval lifestyle is the most common developmental pathway in the animal kingdom. Sea stars, nudibranchs, sea lilies, corals, clams, and barnacles are among the multitude of marine invertebrate organisms that spend days or months in larval form, swimming or drifting near the surface of the world's oceans. For Wray and the other seven scientists who write about larvae this month, these intermediate forms offer beauty, mystery, and a wealth of insight into developmental biology.—*Ellen Goldensohn*

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LETTERS

Word Count

In his article on the evolution of language, *"Homo Grammaticus"* (12/00–1/01), Martin A. Nowak states that "English has about 100,000 words." But an article in the December 2000 issue of *Smithsonian* notes that English has "a total vocabulary of maybe two million words." There is a wide disparity between the two figures. Could you shed some light on which is the more accurate total?
Don Bessette
Wassaic, New York

If I counted every word in the *Oxford English Dictionary*, would I come up with a number reasonably close to the 100,000 quoted by Martin A. Nowak? And would an ordinary seventeen-year-old really know half of these?
H. (Morrie) Kuhlman
via e-mail

THE EDITORS REPLY: Psychologists, linguists, and dictionary publishers use different methods to derive their estimates of the number of words in a language. Nowak's figure is conservative. The roots and stems of words, derivatives and compounds, suffixes and prefixes, proper names, acronyms, and the words for numbers can all come into play when totaling words in a language and when estimating the number of words in an individual's vocabulary. For references, as well as a readable discussion of how some of these variable figures are reached, Nowak recommends Steven Pinker's book *The Language Instinct* (HarperCollins, 1994). Pinker maintains that "people can recognize vastly more words than they have occasion to use in some fixed period of time or space," and he believes that an average high-school graduate would probably be credited with around 60,000 words. Nowak also encourages interested readers to look at W. E. Nagy et al., "The Acquisition of Morphology: Learning the Contribution of Suffixes to the Meanings of Derivatives" (*Journal of Reading Behavior* 25, 1993) and W. E. Nagy and R. C. Anderson, "How Many Words Are There in Printed School English?" (*Reading Research Quarterly* 19, 1984).

Expedition of Two

The note on the 1943–44 Paricutín Expedition to Mexico ("An Expedition Notebook, 1900–2000," 12/00–1/01 supplement) brought back memories, for I went to see that volcano with my sister in August 1944. We went by bus from Uruapan to get as close as possible. When the bus could go no farther, we mounted horses and made our way down a steep incline. Everywhere there was desolation—trees black

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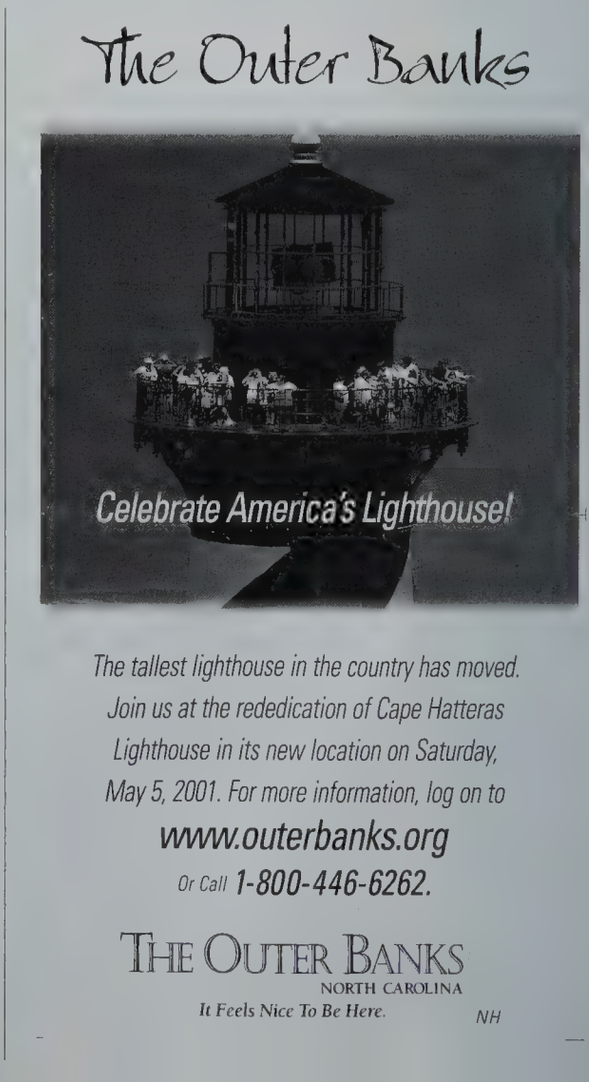
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and bare-limbed and the ground covered with gritty black ash. Such utter desolation, yet, scattered here and there, white mountain poppies managed to push up through the ash.

The lava flow ended abruptly in a jumbled high wall. A short distance away rose the bell tower of a church, all that remained visible of the village of San Juan Parangaricutiro. My sister and I climbed up the ragged lava with great care. From deep crevices we could feel the heat where lava had not as yet cooled from the last flow. By this time it was getting dark, and a misty rain was falling. We made our way over the lava and walked into the shelter of the open bell tower. We stood there in the dark, listening to the roar of the volcano beyond, a sound like continuous thunder, and watched fiery boulders shoot into the air. Some fell back into the crater; others hit the lip and went bouncing down the sides of the volcano in a shower of sparks while behind us the rain spit and sizzled in pockets of still-hot lava. Awesome memories. Thank you.

Doris Hopper
Jacksonville, Illinois

Nerd Humor

I read Neil de Grasse Tyson's article on the laws of physics ("Universe," 11/00) and found his point about the universality of laws based on numerous observations and experiments to be well made. I loved the reference to his old T-shirt bearing the words "Obey Gravity." I have one that states "Why Fight Entropy?" Of course, it is falling apart.

Jim Massa
via e-mail

First Fight

In "Who's on First?" ("Reviews," 7/00–8/00), Anna Curtenius Roosevelt reviews my book *The Settlement of the Americas: A New Prehistory* and E. James Dixon's book *Bones, Boats, and Bison: Archeology and the First Colonization of Western North America*. Readers who are unacquainted with the archaeology of the first Americans may be impressed by Roosevelt's assertions. But in response, I urge them to look at two publications that appeared in a scientific journal and that refute her claims. They are (1) D. J. Meltzer et al., "On the Pleistocene Antiquity of Monte Verde, Southern Chile" (*American Antiquity* 62:4, 1997) and (2) R. E. Taylor and C. V. Haynes, "Radiocarbon Analysis of Modern Organics at Monte Verde, Chile: No Evidence for a Local Reservoir Effect" (*American Antiquity* 64:3, 1999).

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CONTRIBUTORS

The impending birth of his first child inspired **Carl Zimmer** to write about the genealogy of the whole human family (" 'After You, Eve,' " page 32). This article marks the inauguration of *Natural History*'s new bimonthly column "The Evolutionary Front," in which Zimmer explores the latest research and thinking about evolution. For almost two years, Zimmer has been responsible for the magazine's "Biomechanics" column, which will be taken over by other writers following the April 2001 issue. A former senior editor at *Discover* and a contributor to *National Geographic, Science, Audubon,* and *Nature,* Zimmer is the author of *At the Water's Edge: Macroevolution and the Transformation of Life* (Free Press, 1998) and *Parasite Rex: Inside the Bizarre World of Nature's Most Dangerous Creatures* (Free Press, 2000). His next book, to be published this fall by HarperCollins, is the companion to an upcoming PBS television documentary on evolution.

To learn more about *Homo erectus pekinensis,* **Noel T. Boaz** and **Russell L. Ciochon** ("The Scavenging of 'Peking Man,' " page 46) visited the site in China where the remains of this early human relative were discovered and also carefully reviewed the fossils, fossil casts, and related materials stored in museum collections. Collaborating with Chinese paleontologists Xu Qinqi (center) and Liu Jinyi (not pictured), Boaz (right) and Ciochon (left) uncovered new evidence concerning the fate of these Ice Age people and their relationship with the animals that shared their territory. Boaz and Ciochon first met while attending graduate school at the University of California, Berkeley, and "cut their teeth" on bone research by serving on the Omo Research Expedition to southern Ethiopia. Boaz subsequently led expeditions to the Libyan Sahara and to the western Great Rift Valley of Uganda and the Democratic Republic of Congo, while Ciochon has organized expeditions to Myanmar, Vietnam, China, and Indonesia. Boaz is a professor of anatomy at the Ross University School of Medicine in Dominica, West Indies, and Ciochon is a professor of anthropology at the University of Iowa.

Raised in cities and towns east of the Mississippi River, seismologist **Susan Elizabeth Hough** ("The Aftershocks That Weren't," page 64) became interested in earthquakes during her undergraduate years at the University of California, Berkeley, when she discovered that she could put her mathematical talents to use to help solve socially relevant problems. She received her doctorate from Scripps Institution of Oceanography, spent four years as a postdoc at Columbia University, and has worked for the U.S. Geological Survey in Pasadena, California, for the past nine years. Hough (pictured here with her youngest son, Paul) particularly enjoyed her research on the 1811–12 New Madrid quakes, in part because it gave her an opportunity to work with her father, a professor of political science at Duke University. "He helped me to understand the importance of seeing the information from a historical rather than purely scientific perspective," she says. Hough is currently finishing *Earth Shaking Science,* aimed at the general reader and scheduled for publication next year by Princeton University Press.

A native of Ath, near Brussels, **Erik L. Laurent** ("Mushi," page 70) has dual credentials as a zoologist and a cultural anthropologist. He studied the Japanese language in Paris and then pursued fieldwork in Japan. While working in the mountain village of Nagano, he got to know the local silkworm breeders; later, while living in a seaside temple in Kayama, he worked with rice farmers. Wherever Laurent went in Japan, he was impressed with the prominence of insects in the national culture. "You can't escape insects in Japan," Laurent says. "They eat crops, and some, such as locusts, are eaten by people. They figure in poetry and novels as symbols of life, death, and change." Having spent a decade of fieldwork on *mushi,* Laurent now plans to study human sexuality in Japanese culture.

James Warwick ("The Natural Moment," page 88) started taking photography seriously in 1995, just after graduating from the University of Oxford with a degree in materials science. He was inspired by a trip to Kenya and has since made excursions to the Kalahari Desert, Namibia, and India. Most recently he visited the Wolong Nature Reserve in China to photograph pandas. Warwick strives for evocative ways to capture his subject. In his image of a starling flock over Brighton's West Pier, taken with a Nikon F90X and a 28–80mm lens, he used a slow shutter speed that helped to give "an Impressionist feel to the composition." Warwick (www.jameswarwick.co.uk/) won two awards in the 1998 BG Wildlife Photographer of the Year competition, and his work has appeared in journals worldwide. He resides on the coast of the English Channel, not far from the West Pier.

An associate professor of biology at Duke University, **Gregory A. Wray** ("A World Apart," page 52) wrote on sea stars and other echinoderms in the December 1998–January 1999 issue of *Natural History*. That article ("Body Builders of the Sea"), coauthored with Rudolf A. Raff, prompted our editors to put together the present set of articles on marine invertebrates. Wray, right, continues to study the evolution of developmental mechanisms in echinoderms (as well as in ants). The peculiar anatomy of marine larvae was what first sparked his interest in asking how natural selection shapes the way an animal develops, a question that led in turn to his current research on the evolution of gene networks in embryos and larvae. Wife and husband **Elizabeth J. Balser** and **William B. Jaeckle** ("And Then There Were Two," page 54) are assistant professors in the department of biology at Illinois Wesleyan University in Bloomington, Illinois. They welcome the chance afforded by ocean plankton to explore the diversity of larval form and function and hope soon to identify, down to the species level, the cloning larvae they are studying. Balser provided the videos of marine invertebrate larvae viewable on *Natural History*'s Web site (www.naturalhistory.com) this month. **Steven Morgan** and **Skyli McAfee** ("Getting to the Point," page 57), another husband-and-wife team, are researchers at Bodega Marine Laboratory in California. Morgan is also an associate professor in the department of environmental science and policy at the University of California, Davis; McAfee is currently studying white sharks off the California coast. Most of Morgan's research has centered on the complex dynamics of populations at the land-sea margin—a focus he feels is essential if we are to "fully understand, and conserve, marine life in the face of a burgeoning human population." **Larry R. McEdward** ("The Long and the Short of It," page 58) is an associate professor in the department of zoology at the University of Florida. He conducts research on echinoderm larvae in the Florida Keys and the San Juan Islands of Washington State. His recent research has involved about equal parts diving, lab studies, computer modeling, and mountain biking. A senior scientist at Harbor Branch Oceanographic Institution in Fort Pierce, Florida, and head of the institution's department of larval ecology, **Craig M. Young** ("Out of the Frying Pan, Into the Freezer," page 61) has participated in more than sixty deep-sea research cruises and has visited the seafloor more than a hundred times. He is senior editor of *The Atlas of Marine Invertebrate Larvae,* forthcoming in July from Academic Press. **Richard Strathmann** ("A Method for the Masses," page 62) is a professor of zoology and associate director of the Friday Harbor Laboratories on San Juan Island. He explains his interest in marine embryos and larvae very simply and in a way that is surely true for all his colleagues: "Because they are beautiful and I want to understand their form." Inspired by early-twentieth-century English embryologist and poet Walter Garstang, Strathmann encourages his students to write poems of their own about larvae.

IN SUM

DADDY'S NO BOOB According to some evolutionary biologists, males will act to favor the reproduction of their own genes at the expense of their rivals' genes. Male blue-footed boobies provide extensive parental care, including defending the nest, incubating the eggs, and helping to feed the chicks.

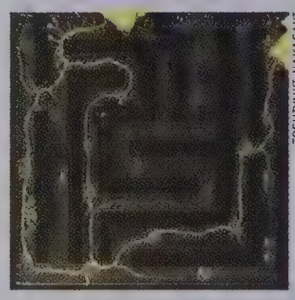
How can males prevent their prodigious labors in the seabird colony from profiting other males that may try to cuckold them while they are off gathering food? According to Marcela Osorio-Beristain and Hugh Drummond, of the Universidad Nacional Autónoma de México, when an egg's paternity is in doubt, some male boobies push it out of the nest.

To test the male birds' reactions to eggs that may have been fertilized in their absence, the researchers (working on Isla Isabel, off Mexico's Pacific coast) removed a number of males from their nesting territory for ten to twelve hours and then returned them to their mates. One group of males was removed a few days before their females' fertile period (about a week before females lay their eggs); a control group had been temporarily isolated several weeks earlier. The scientists found that females did not suddenly become promiscuous while their mates were away. Some copulated with other males, but the rate of these pairings was low. Yet of the males sequestered just before the females' fertile period, 43 percent expelled the first-laid egg from the nest, although none of the control males did so.

MARK JONES

The researchers concluded that a large proportion of male boobies will eliminate any possibility of lavishing their efforts on a "deadbeat dad's" offspring by destroying eggs of questionable paternity—even though some of them could be their own. ("Male Boobies Expel Eggs When Paternity Is in Doubt," *Behavioral Ecology* 12:1, 2000)

SMART SLIME Scientists at the Bio-Mimetic Control Research Center in Nagoya, Japan, placed blobs of the single-celled amoeba-like organism *Physarum polycephalum* inside a miniature maze in which four different routes led to food (ground oat flakes) placed at the start and end points. In a series of trials, the slime organism consistently chose the shortest path to reach the prize.


TOSHIYUKI NAKAGAKI

Maze-solving slime

Classified as fungi, slime molds seem to share characteristics with both plants and animals. Like other fungi, they reproduce with spores, yet like amoebas, they can change shape and extend pseudopodia—tubelike legs with which they reach out to move and to absorb food. When pieces of a *P. polycephalum* were placed in the maze, they spread and coalesced to form a single organism spanning the shortest route from start to end. Then the mold extended its pseudopodia to connect the two food sources, reaching for a double helping.

The research team, led by Toshiyuki Nakagaki, concluded that the organism changes shape to maximize foraging efficiency, eventually forming one thick tube covering the shortest distance between food sources—a "cellular computation" demonstrating a "primitive intelligence." ("Maze-Solving by an Amoeboid Organism," *Nature* 407, 2000)

BALLISTIC TONGUE Chameleons are well known for being able to change color but also for their spectacular ability to capture prey by shooting out their long, sticky tongues. While many other kinds of lizards can extend their tongues to seize small prey, only chameleons have evolved a powerful suction device: a pouch on the lingual tip. This pouch enables them to grab birds and lizards as heavy as 15 percent of the chameleons' body weight—a feat comparable to a 150-pound man lifting a 22-pound weight with his tongue. Using high-speed video, X rays, and electromyography, a team led by Anthony Herrel, of the University of Antwerp, and Jay Meyers, of Northern Arizona University, has elucidated the mechanism in various chameleon species.

Herpetologists already knew that chameleons had a pair of pouch-retractor muscles in their tongues, but it was thought that the pouch splayed open on contact with prey, creating suction. Herrel, Meyers, and colleagues have shown that these muscles actually open the pouch just before contact and that two modified muscles then pull the tongue pad inward. (When the researchers cut the special nerves that extend into the pouch-retractor muscles, the chameleons were unable to hold onto their targeted meal.) These intricate, coordinated movements, including the full retraction of the tongue with its captive, are completed in less than half a second. The suction adaptation, the team believes, arose when the lizards took to the trees, where targeted prey would fall if not instantly well secured. ("The Mechanics of Prey Prehension in Chameleons," *Journal of Experimental Biology* 203, 2000)

—Richard Milner

X ray of a chameleon extending its tongue

JAY MEYERS AND ANTHONY HERREL

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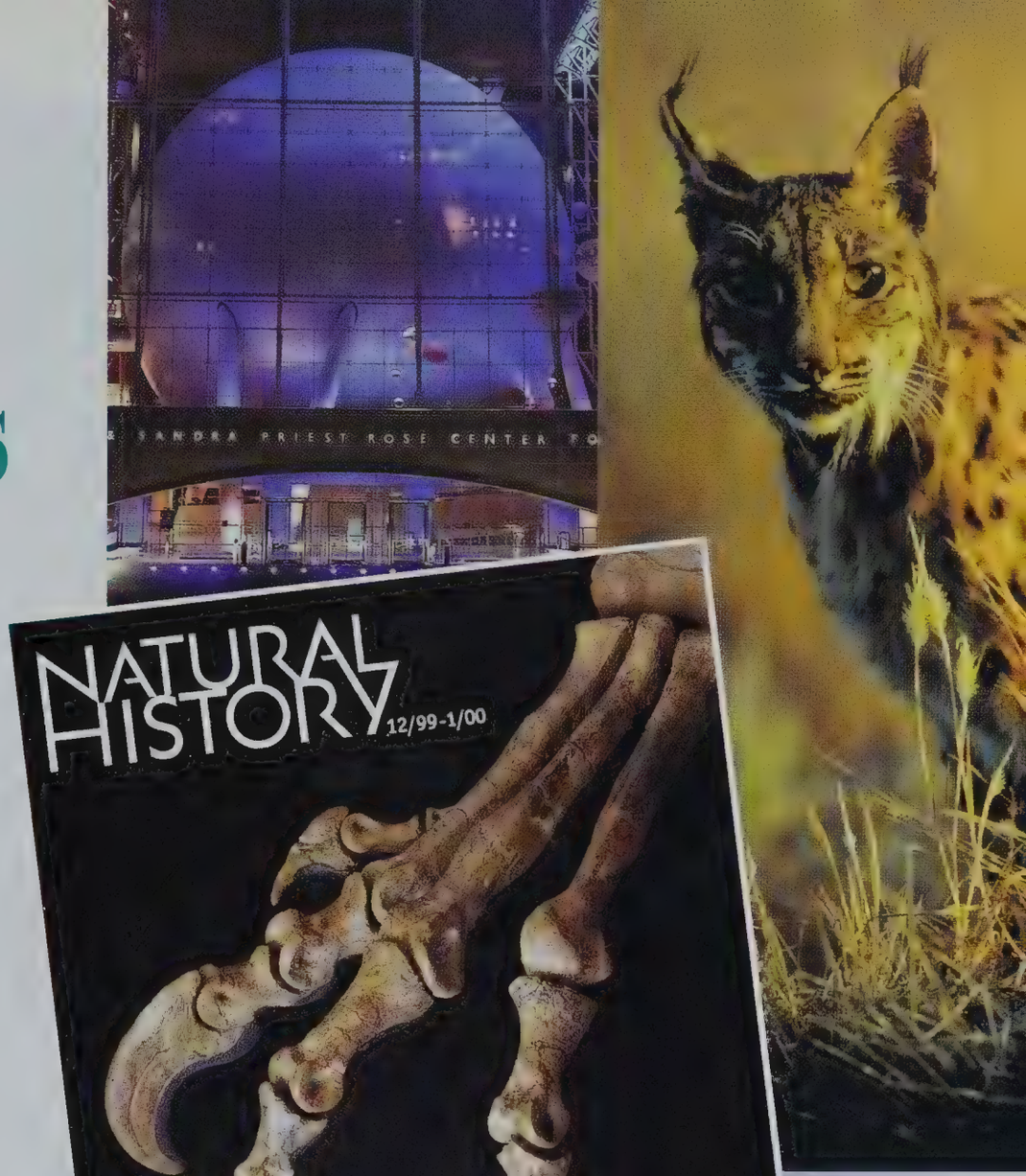

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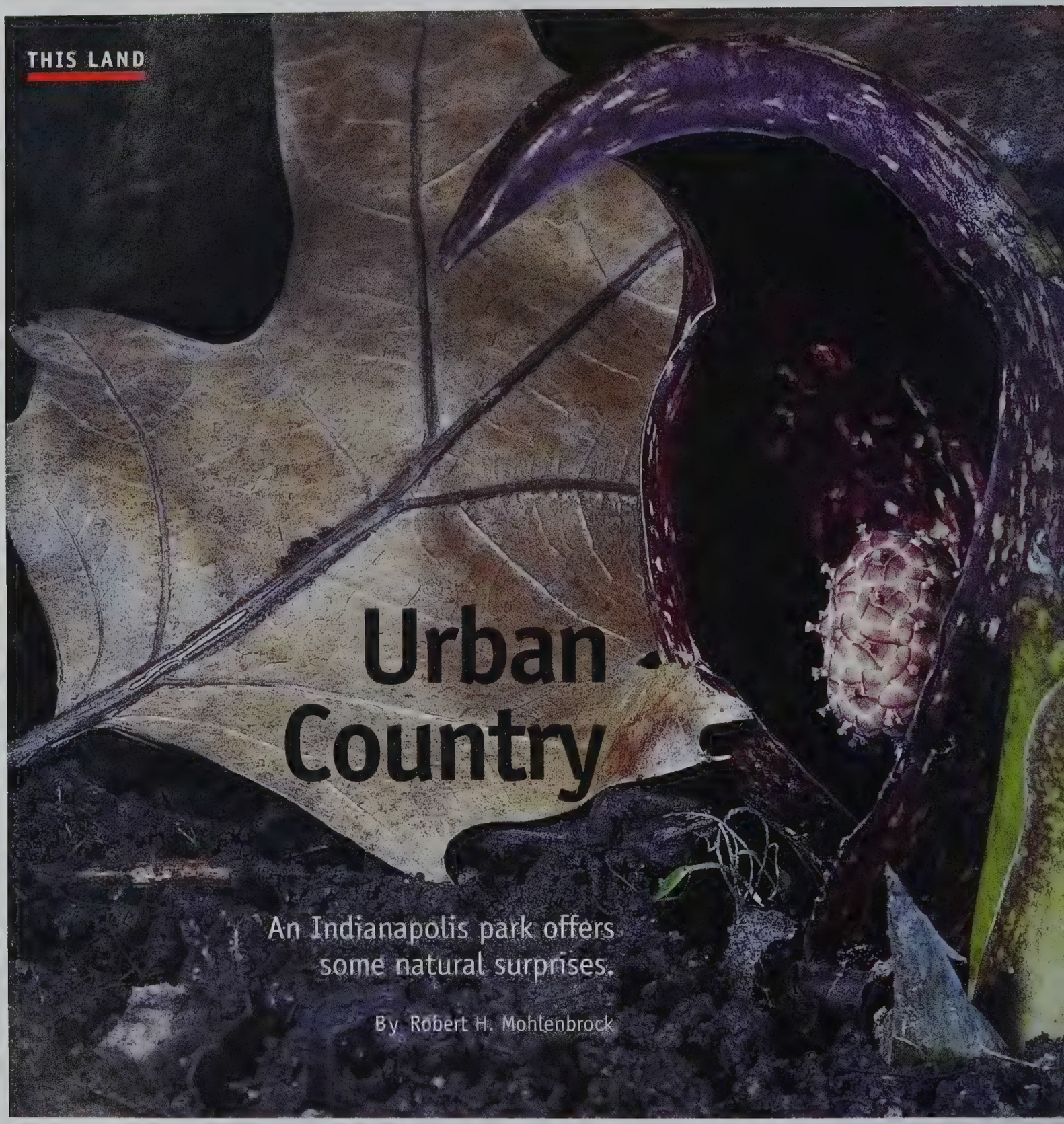


THIS LAND

Urban Country

An Indianapolis park offers some natural surprises.

By Robert H. Mohlenbrock

In 1916 John Holliday, who founded the *Indianapolis News* and the Indiana National Bank, donated his country estate to Indianapolis for family recreation and nature study. Today, managed by the Indianapolis Department of Parks and Recreation (IndyParks), it provides an enclave within the city limits where local residents and visitors to the state capital can sample an array of natural habitats. Covering eighty-three acres, Holliday Park borders Indiana's White River, which originates near the state's eastern edge and snakes southwest, taking a circuitous route through Indianapolis and finally emptying into the Wabash River. The heavily wooded park is crisscrossed by trails, some with boardwalks that help the hiker negotiate the wetter zones.

When the White River is at normal stage, it is bordered by a

JAMES P. ROWAN

Skunk cabbage

narrow, muddy beach. Wetland plants grow in shallow water nearby, while the inland floodplain is covered with tree species that can tolerate periodic flooding. Farther off, low hills are home to a drier, upland forest containing a wide variety of trees, shrubs, and wildflowers.

Because of the unique structure of its seed capsules, lopseed *(Phryma leptostachya),* a wildflower of the upland woods, has a family classification all its own. Most botanists believe it is distantly related to verbenas. It has pink blooms and, for a plant that is often less than a foot tall, relatively large leaves. The seed capsules, shaped somewhat like parrots, lie flat against the stem and point straight down.

Several natural springs on the hill slopes yield clear, cool water that trickles in rivulets toward the river. A mesic (moist) forest, where wildflowers bloom abundantly in spring, covers a small area near the foot of the hills. And at the convergence of the rivulets is an extensive wetland known as a fen, a boglike habitat more frequently found in northern Indiana, northern Illinois, Michigan, and Canada.

Whereas bogs are acidic, the water in a fen is basic, owing to the presence of bedrock composed of limestone or dolomite. Some wetland plants do well in either habitat, but others are more restricted. Plants at Holliday Park that are usually confined to fens are swamp blue aster, speckled joe-pye weed, and a rather rare species of pink turtlehead.

Stepping out of Holliday Park and heading south just one mile, visitors will encounter a historic residential zone that lines Meridian Street. With its huge homes, this narrow, tree-lined corridor between 38th Street and 57th Street is an elegant reminder of Victorian-era Indianapolis.

Robert H. Mohlenbrock, professor emeritus of plant biology at Southern Illinois University, Carbondale, explores the biological and geological highlights of U.S. national forests and other parklands.

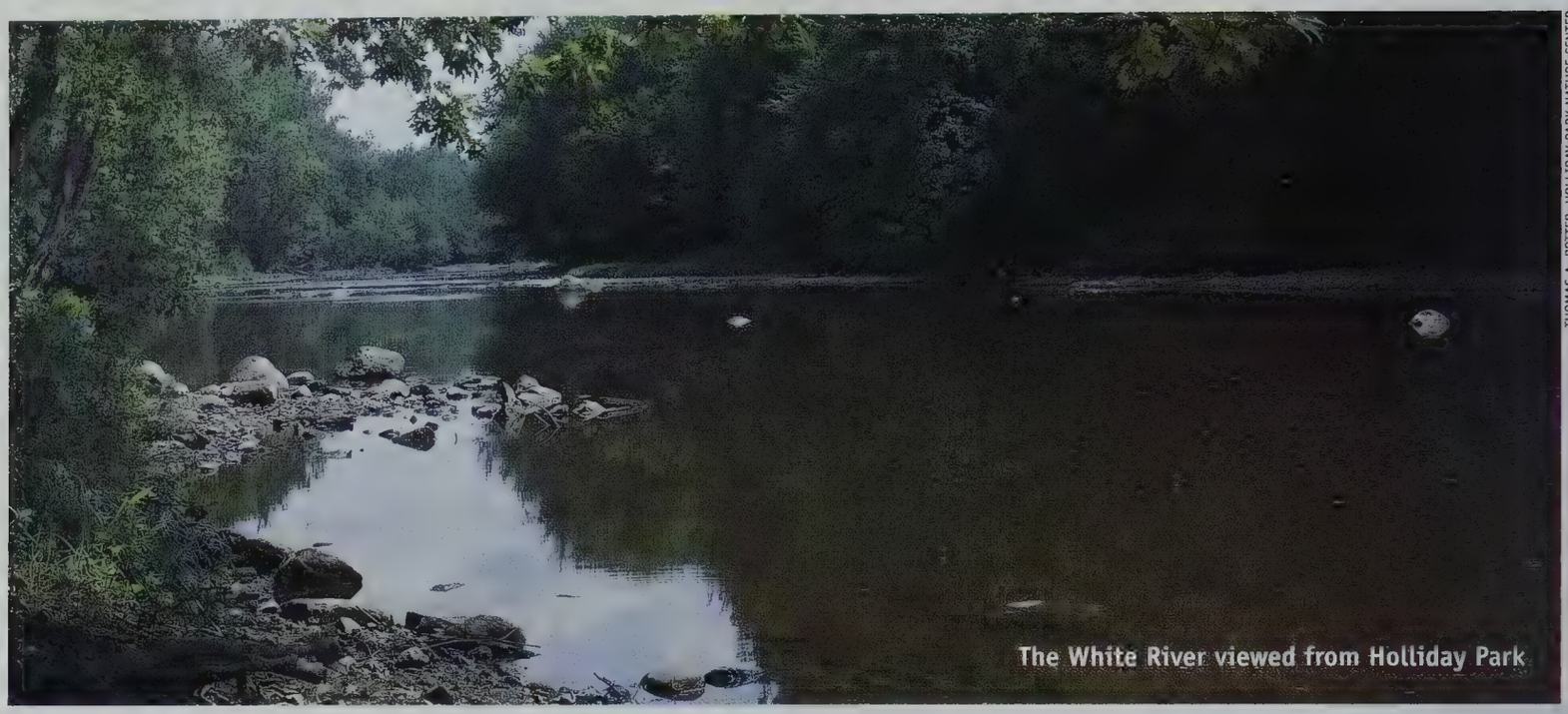
For visitor information, contact:
Holliday Park Nature Center
6363 Spring Mill Road
Indianapolis, IN 46260
(317) 327-7180
www.indygov.org/indyparks

HABITATS

Shoreline plants include soft-stem bulrush, hardstem bulrush, river bulrush, and an aquatic, purple-petaled wildflower known as water willow. Although its somewhat narrow leaves are similar to those of willow trees, water willow is actually a member of a small group of colorful flowering plants related to wild petunias (which, incidentally, are unrelated to cultivated petunias).

Floodplain forest is thick with green ash, American elm, sycamore, cottonwood, and silver maple, with box elder near the water's edge. In early spring, white-flowering bulbous cress and waxy yellow swamp buttercup provide bright splashes on the forest floor. By mid-May, coarse herbs begin to fill the understory, and in summer their junglelike growth can make hiking difficult. A further deterrent is the prevalence of wood nettle and stinging nettle, which have acid-tipped hairs on their stems and leaves. Another nettle, known as golden glow, is a robust plant whose late-summer flower heads resemble those of its cousin, black-eyed Susan, except that those of golden glow have a yellow rather than a brown center.

JOE LEMONNIER


The White River viewed from Holliday Park

THOMAS A. POTTER; HOLLIDAY PARK NATURE CENTER

Mesic forest is dominated by Ohio buckeye, green ash, tulip poplar, and sugar maple. Here and there is a blue ash, unusual among ashes because of its square twigs. The dense shade of the trees creates a rich habitat for moisture-loving shrubs and wildflowers. Spicebush, with its pleasantly scented leaves, and bladdernut, with its inflated fruits, are the chief shrubs. One bladdernut growing here is certainly among the largest of its kind in the world, having a trunk diameter of six inches. The wildflowers, many of which bloom in May, include waterleaf, wild ginger, red trillium, Jack-in-the-pulpit, smooth and woolly blue violet, Solomon's seal, false Solomon's seal, and enchanter's nightshade. Missouri ironweed, zigzag goldenrod, arrow-leaved blue aster, and late boneset provide a second wave of blossoms in autumn.

Upland woods contain red mulberry, slippery elm, white ash, and wild black cherry. Black oak, red oak, chinquapin oak, bitternut hickory, and pignut hickory are common near hill summits, where the driest conditions prevail. Spring-blooming wildflowers are the broad-leaved spiderwort, downy yellow violet, and hairy phlox. Few plants flower in the upland woods during the summer, although lopseed is fairly common.

Fen plants include watercress and wild forget-me-not, which grow in clear, flowing water. Watercress, whose leaves are a delicacy in salads, has flowers with four white petals; wild forget-me-not has five-petaled blue flowers with a yellow center. Broad-leaved arrowhead and lizard's-tail are found where the water is deepest, while skunk cabbage, with its huge leaves, lines the perimeter of the fen. A typical wildflower is obedient plant (so named because its flowers can be turned in any direction and, once released, will remain there for some time). Others are swamp blue aster, a pink turtlehead *(Chelone obliqua),* speckled joe-pye weed, great lobelia, Pennsylvania buttercup, and several kinds of sedges. Black ash is the only tree species—one that is rare in central Indiana but more common in the northern counties.

Solomon's seal

A.B. SHELDON; DEMBINSKY PHOTO ASSOCIATES

Ohio buckeye

RICHARD SHIELL; DEMBINSKY PHOTO ASSOCIATES

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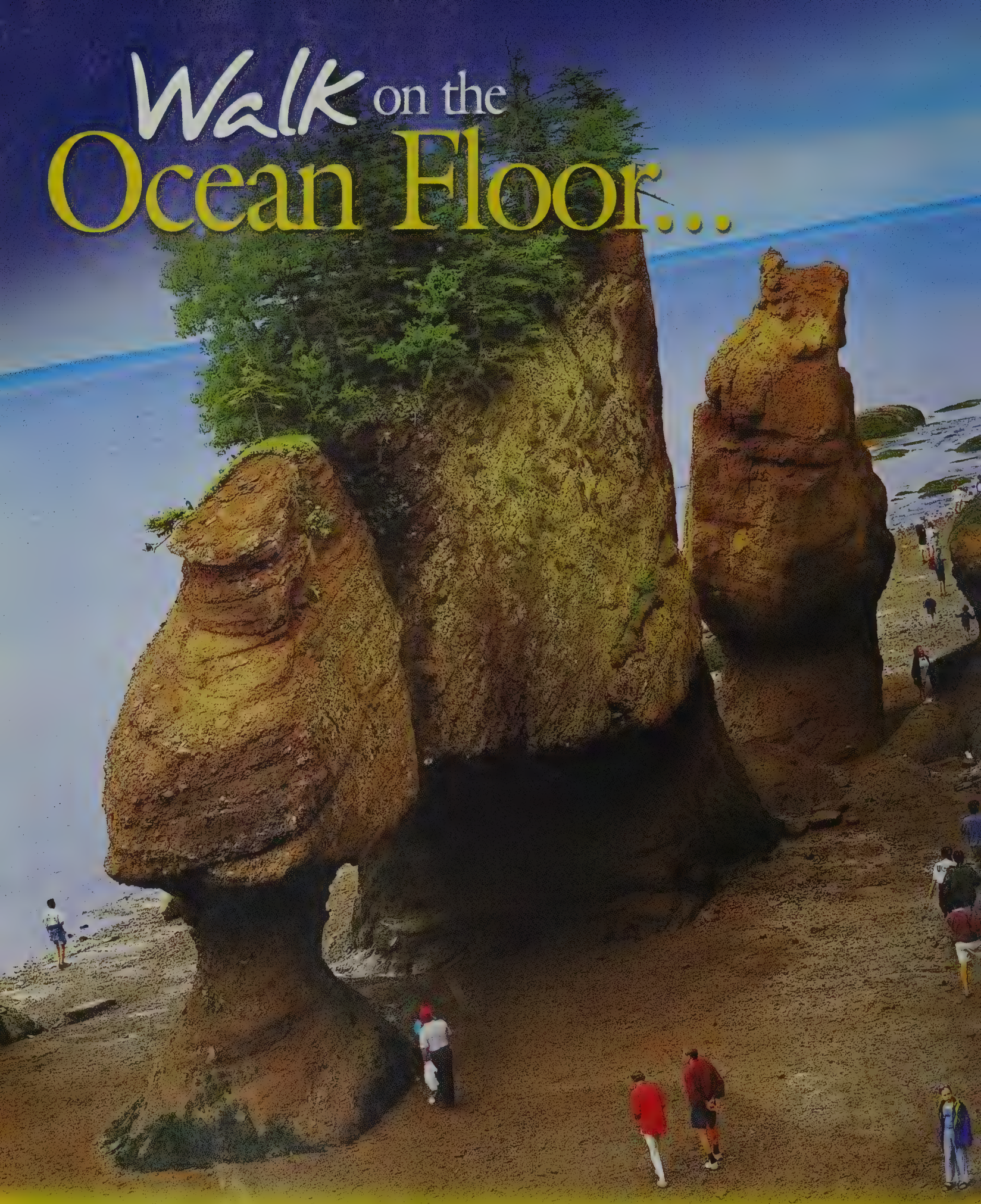

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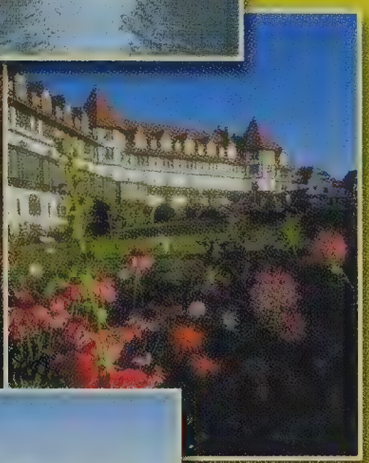

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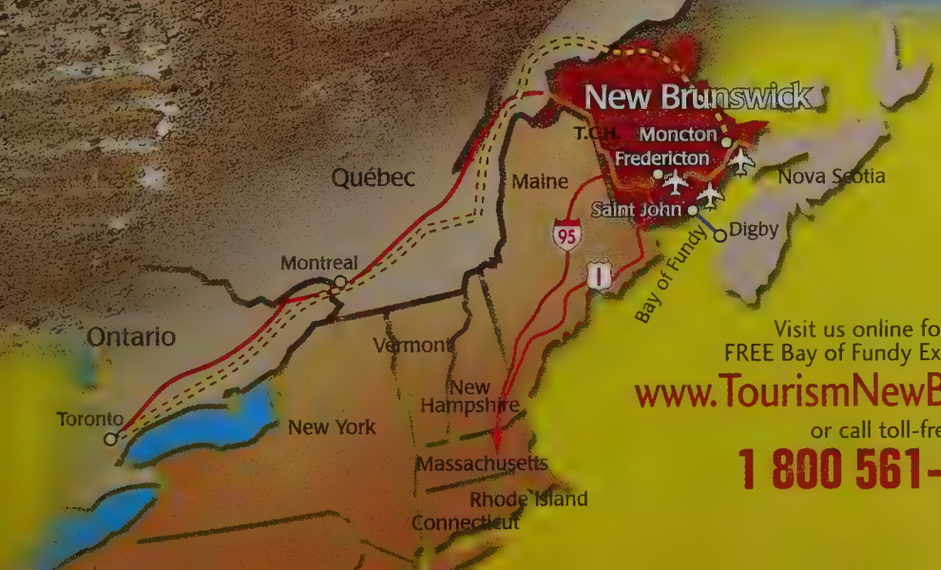

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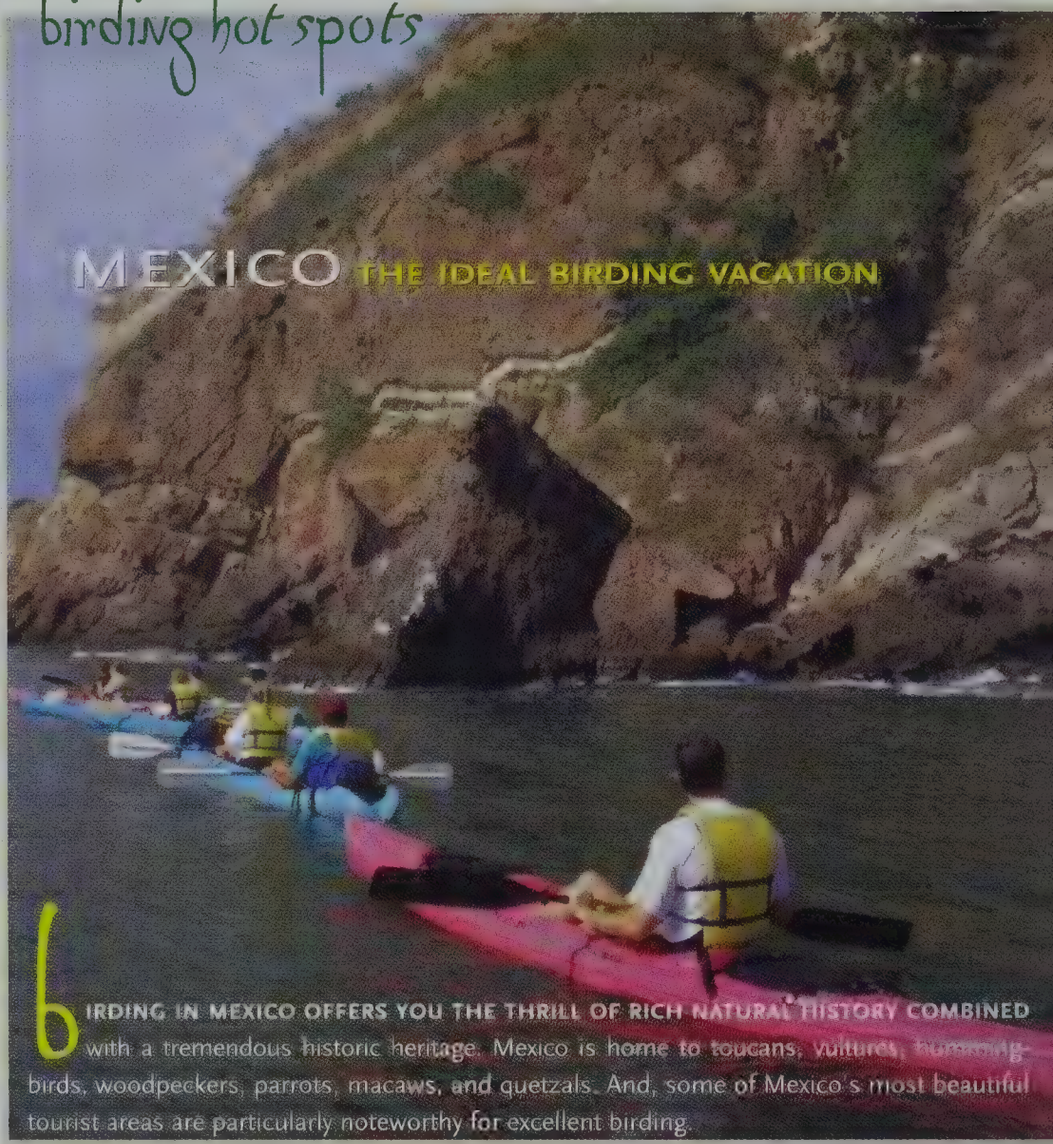

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An ideal place to start your journey is Mazatlan. The gateway to the Sea of Cortez, Mazatlan is bounded by the majestic Sierra Madre Mountains. Its diverse habitats include beaches, wetlands, and forests. Here you'll be treated to a variety of endemic species including the blue-footed booby and red-billed tropicbird on the offshore islands, and the tufted jay and redheaded tanager in the mountains.

Another location that is quickly becoming a popular ecotourism destination is the Copper Canyon, part of the Pacific slope of the Sierra Madre. Home of the Tarahumara Indians, the Copper Canyon is one of the largest and most complex canyon systems in the world. Its many distinctive habitats offer some of the most wonderful resident, migrating, and wintering bird species in the area.

For a glimpse of Mexico's southern birds, visit the Calakmul Biosphere Reserve. The reserve protects endangered tropical forests in Mesoamerica and is home to 350 different kinds of migratory and native birds, including the threatened great curassow, as well as howler and spider monkeys.

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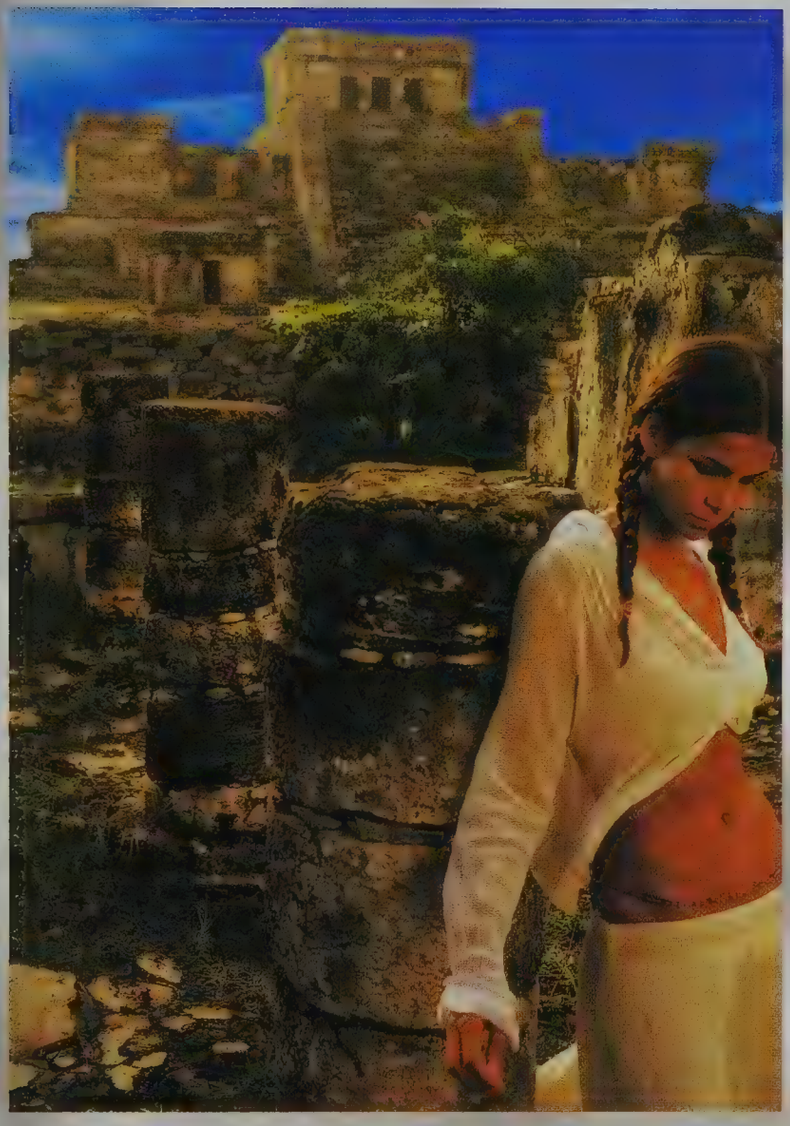
Photographs by Doug Wechsler ©VIREO

I was born thousands of years ago, and soon I taught the world to count the days by the sun, the months by the moon, and the years by the stars. **Today I am affectionately called México, and I am full of intrigue and wonder.**



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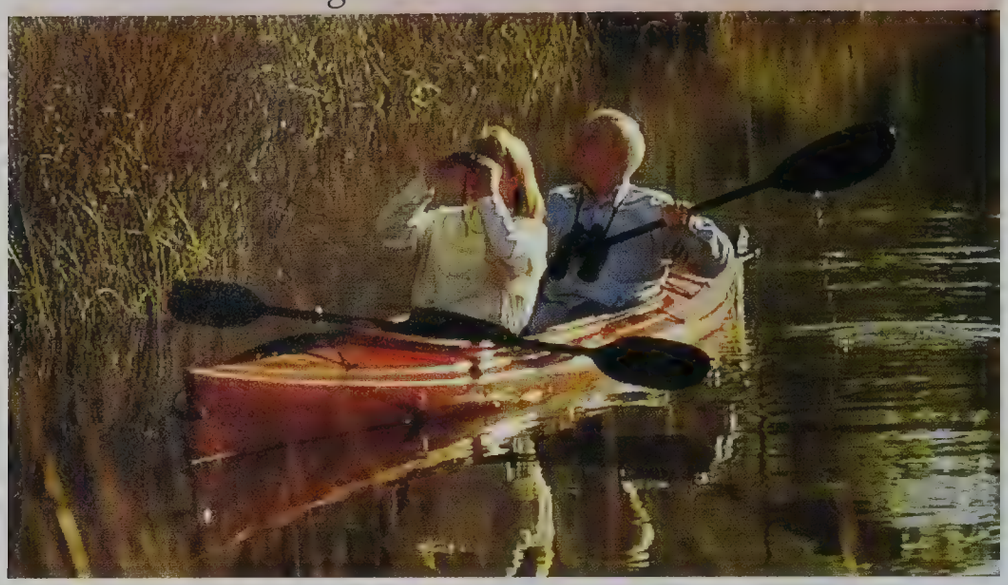

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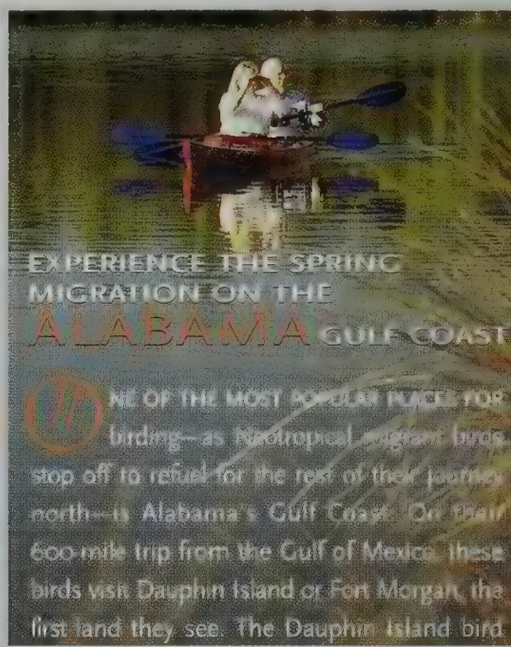

ONE OF THE MOST POPULAR PLACES FOR birding—as Neotropical migrant birds stop off to refuel for the rest of their journey north—is Alabama's Gulf Coast. On their 600-mile trip from the Gulf of Mexico, these birds visit Dauphin Island or Fort Morgan, the first land they see. The Dauphin Island bird card lists 345 species, about 85 percent of the state list; it's not unusual to see 20 species of warblers. Fort Morgan is a classic migrant trap, and a birding paradise when adverse weather forces birds down in a "fallout," especially in the spring. To find out more call **800-745-SAND** or **www.gulfshores.com**. ✧

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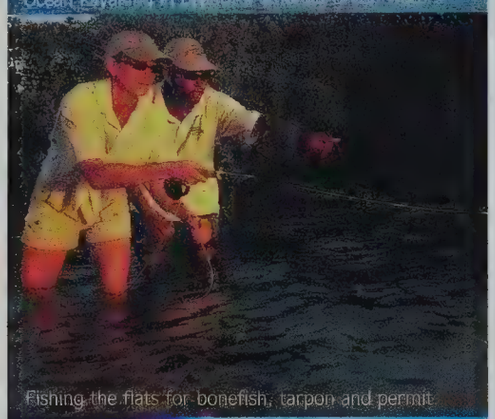
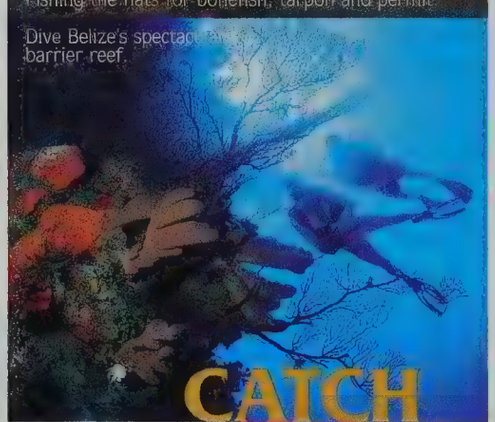
Ocean kayaking in Laughing Bird Caye National Park


Fishing the flats for bonefish, tarpon and permit.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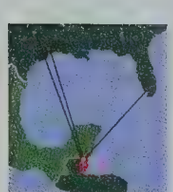

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Skokholm is Britain's oldest bird observatory, and its lighthouse, built in 1916, has been especially adapted to protect the thousands of manx shearwaters that return to the island after dark. The spring and fall migration periods can be spectacular, with "fallouts" of common birds such as larks, thrushes, warblers, flycatchers, pipits, and finches, depending on the season and the weather.

For more information on birding in Wales, contact the British Tourist Authority at **1-800-462-2748** or **www.visitbritain.com**. ✧

BELIZE THE BIRDER'S PARADISE

WITH ECOSYSTEMS as diverse as swamplands and tropical forests, this small country boasts not only 540 species of birds but also some of the most exotic and rare. Much of the wildlife found in Belize is thriving, thanks to the protected areas that make up more than 40 percent of the country.

One very special area that birders won't want to miss is the Crooked Tree Wildlife Sanctuary, a wetland preserve in the north-central part of the country that is home to more than 250 species. A wonderful example of successful ecotourism, the sanctuary was founded by the village of Crooked Tree's 750 residents, many of whom now earn a living by helping visitors learn more about their region. Chau Hiix Lodge is one of the properties in Crooked Tree that caters exclusively to birders, offering package rates that include all meals and guide services.

If you're interested in forest birds, a unique conservation organization called Programme for Belize devotes 260,000 acres of rain forest to research, education, and includes a wildlife sanctuary as well.

Plan to stay at Chan Chich, an upscale lodge that is set on the plaza of an ancient Maya site. There, blue crowned mot mots, Scott's orioles, Montezuma oropendulas, and many kinds of colorful parrots will serenade you as you enjoy this birder's paradise. A 10-mile network of nature trails provides plenty of opportunity to explore this unique area.

TO OBSERVE SOME COASTAL SPECIES, visit the popular island of Ambergris Caye, an ideal base for observing the birds that live along Belize's 185-mile- long barrier reef. You can stay at the Caribbean Villas, a seaside hotel that boasts a five-level "people perch" that allows you to peer into the island forest.

For more information about Belize, contact the Belize Tourism Board at **800-624-0686**, or go to **www.travelbelize.org**. ✧

This special editorial/advertising supplement was created by the Natural History Special Sections Department and did not involve the magazine's editorial staff. **WRITER:** *Stephanie Fekety* **DESIGN:** *Mindy Phelps Stanton*

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IN THE FIELD

JIM BRANDENBURG; MINDEN PICTURES

Beaver lodge, Minnesota

Warm Welcome

A beaver's lodge is its castle, particularly when ice covers the pond.

By Peter J. Marchand

Northern winters can be long for a beaver—longer than for most nonhibernating mammals. Though equipped to gnaw through the hardest wood, beavers show little inclination to chisel through ice and thus are seldom seen from the time their ponds freeze over until spring melt, often long after snow has left the land. Yet beavers rarely die during the winter from cold stress or a shortage of food. The key to their success in the North seems to lie, in large measure, with their lodge—the most massive communal nest constructed by any animal.

Not until I actually crawled inside a lodge did I understand the full implications of this structure for a beaver's life under ice. My opportunity came early one winter in northern Vermont as a result of an unusual circumstance. Just before freeze-up, a local highway maintenance crew had rifted a colony's dam to prevent the flooding of a road. When the pond's water level dropped below the entrances to their lodge, the beavers, rather than attempting to repair the dam, vacated the premises. A month later, my students and I ventured onto the frozen pond to investigate the lodge and found the exposed entrances. We couldn't resist the temptation. Shedding some of our bulky clothing, two of us wiggled and squirmed (with an occasional push from behind by others) into opposite tunnels until we met in the middle.

That firsthand inspection gave me an insight into the winter lives of beavers that none of my previous studies had ever provided. Outwardly, a beaver lodge appears to be nothing more than a mud-plastered pile of woody debris—an unkempt heap of odd-sized sticks that occasionally reaches twenty feet in diameter and rises four or more feet out of the water. In this case, the interior turned out to be a marvel of neatness and cleanliness. The earthen floor of the lodge was worn smooth by the countless comings and goings of wet feet on silky clay. The walls and ceilings were trimmed evenly; not a single nub protruded to discomfort a huddling animal (which explained why the beavers in lodges I'd previously attempted to study had been so quick to chew off the ends of some temperature probes I'd inserted). A small chamber branched to the side of one entrance tunnel, apparently having served as a feeding platform just above the water level. It held a single scrap of food: a frozen aquatic quillwort, still whole and green. The main nest chamber, roomy enough to permit us to raise our heads and pass a camera back and forth between opposite tunnels, was devoid of any detritus—not a trace of food, fecal material, or odor.

The lodge had been empty for some time, but my initial sensation upon entering it was one of subtle warmth. Heat, conducted upward from the unfrozen water beneath the floor, maintained the temperature near the freezing point—considerably warmer than the snowy world outside. It was easy to imagine the relative comfort of an occupied chamber. A family of beavers crowded into a small space, huddling and grooming, can generate significant heat (it is not unusual for a pair of adults and two litters of kits to winter together). On a zero-degree day, I once recorded a lodge temperature of 60° F, well within a beaver's thermoneutral zone (the temperature range within which an animal can remain comfortable without raising its metabolic rate) and warm enough to melt a hole in the snow at the top of the lodge.

But there's another, colder side to this picture. Beavers face an energy dilemma every time they slip into the icy water for an excursion to their food cache. (In the fall, beavers stockpile tree branches underwater.) The compression of their fur in the water and the resultant displacement of air from the otherwise superbly insulated pelt, coupled with water's high capacity

to conduct heat, greatly accelerate heat loss from the beaver's body and can render the animal hypothermic within about thirty minutes. The need to procure food can become a repeated trauma for the kits, which may enter the water daily in feeding forays lasting from less than five minutes to more than forty. (Adults may make fewer trips, subsidizing their energy needs with fat stores in the tail.) A foraging beaver benefits by being able to return to a warm lodge, where its body temperature can be quickly restored to the requisite 98° F.

But herein lies a potential problem. Four hundred cubic feet of earthen lodge, if allowed to cool, can quickly turn into a massive heat sink instead of a life-saving refuge. One way to prevent this might be for family members to stagger their foraging trips, ensuring that the lodge is occupied at all times—and this is where an unusual aspect of beaver behavior comes into play.

To maximize effectiveness in functions such as feeding and mating, virtually all animals maintain biological rhythms that are precisely cued to day length and seasonal cycles. Scientists aren't sure why or how, but beavers' biological clocks (and thus their activity patterns) drift out of phase with the day/night cycle in winter. Although long isolation in the lodge without external light cues would promote such drift (and I can attest to the darkness of a lodge interior), even infrequent excursions underwater should recalibrate internal clocks, since light easily penetrates ice and snow cover on a pond. Yet all across southern Canada and the northern United States, beavers display winter activity patterns based on a twenty-six- to twenty-nine-hour cycle, resulting in a considerable shift, over time, in their daily schedules. Having a free-running internal clock probably carries little risk under the ice, where predators are not a threat, but what is the advantage? One possibility is that in winter, staggered foraging times may maintain an equable indoor temperature, guaranteeing a warm welcome whenever a beaver returns to its lodge.

Peter J. Marchand is currently a visiting scientist at the Carnegie Museum of Natural History's Powdermill Biological Station near Rector, Pennsylvania.

JIM BRANDENBURG; MINDEN PICTURES

Beavers with an aspen branch, a favorite food

THE EVOLUTIONARY FRONT

"After You, Eve"

Research on the Y chromosome only hints at the complexity of the human genealogical tree.

By Carl Zimmer

My wife, Grace, and I are expecting our first child in July, so I've had a lot on my mind recently. Most of it has been pretty mundane stuff: What's the fastest route from our apartment to the hospital? How exactly do you swaddle a baby? But sometimes loftier thoughts invade. I think about our child as the union of two heritages. My wife's flows back to Ireland, to County Kerry in the south and County Derry in the north. My own heritage is more far-flung, encompassing Wales, England, Germany, and Hungary, as well as countries in eastern Europe that no longer exist, having been bisected and trisected by countless wars.

Both our family trees extend back only a few generations, at which point written records and the memories of relatives fail. But we, like all other humans, also carry a genetic genealogy. Encrypted in our DNA is a history of our species. Scientists are learning how to decode that history, and they find that if you go back far enough in time, my wife's heritage and my own eventually fuse, along with that of the rest of humanity.

There's an apparent paradox in our molecular genealogy, however: different genes tell different stories. Research on one set of genes indicates that all humans on earth descend from an African woman who lived 170,000 years ago. Scientists studying a different group of genes recently concluded that all humans descend from an African man who lived 59,000 years ago. Even allowing for a healthy margin of error in these estimates, it would seem that Eve lived more than 100,000 years before Adam.

You might think that the scientists involved need to find the mistake that produced two such different conclusions. But as contradictory as the results may appear, they are perfectly compatible. Genealogy is much stranger than most of us realize.

The quest for humanity's genetic

JAMES MARSH

genealogy began in the early 1980s, when researchers were just starting to decipher the genetic code. DNA is shaped like a twisted ladder, and each of its rungs is made of a pair of building blocks called bases. When scientists began to read the sequence of these base pairs, some of the first genes they chose to decode were a peculiar sort. Nearly all of our 30,000 genes are located within the cell nucleus. But 37 genes reside outside the nucleus, in sausage-shaped structures known as mitochondria, which act as the powerhouses of the cell.

These outlying genes are also unusual because of the way they are inherited. The genes in a human cell nucleus are arranged on twenty-three pairs of chromosomes. At the time an egg or a sperm cell is being formed though cell division, the chromosomes in each pair swap parts of their genetic material (with one important exception, which I'll get to later). Each egg or sperm then receives only one from each pair of rearranged chromosomes. When a sperm fertilizes an egg, it contributes its chromosomes, and a new set of twenty-three pairs is established. Thanks to the swapping episode, it's a unique combination of genes.

Mitochondria are different. Mitochondria themselves do not engage in sexual reproduction. Moreover, a father cannot contribute mitochondrial genes to a child, because mitochondria in sperm can't enter the egg cell. My child inherited only my wife's mitochondrial genes, my wife inherited her mitochondrial genes only from her mother, and so on, back through thousands of generations of women.

In the mid-1980s Allan Wilson, a geneticist at the University of California, Berkeley, recognized that the genes in mitochondria were loaded with historical information that other genes lack. Our chromosomes go through a complex shuffle in every generation, but mitochondrial genes create a clean, unmuddled pedigree. The only way a difference between the mitochondrial genes of a mother and her child can arise is if they mutate. In some cases, a mutation will cause a genetic disorder with symptoms such as weakness, respiratory problems, or deafness. Natural selection steadily removes the most harmful of these mutations from the human gene pool. On the other hand, mutations can alter mitochondrial genes without causing harm (and, in very rare cases, may even bestow some benefit). If a woman acquires a harmless mutation in her mitochondrial DNA, she will pass it on to her children, and her daughters will pass it on to their own children. It will mark her descendants as distinct from other people—distinct even from the descendants of her own sister.

Mitochondrial Eve's genes came to dominate our species much the way one surname can take over an entire village.

Wilson and his students studied some of these markers by gathering samples of mitochondrial DNA from people around the world and comparing specific stretches from each individual. They found that different groups of people shared certain markers, suggesting that these groups had descended from a common ancestor. For example, Europeans all shared markers that no one else did, while Asians had unique markers of their own. Wilson's team also found that Asians and Europeans shared certain other markers that Africans lacked. By grouping people on the basis of their markers, Wilson's team was able to construct an evolutionary tree for humanity. The branches that sprouted closest to the base of the tree were all African lineages, suggesting that mitochondrial DNA in all humans living today descended from an African woman.

Wilson's team named not only the place, but also the time, of human origins. "All these mitochondrial DNAs stem from one woman who is postulated to have lived about 200,000 years ago, probably in Africa," they announced in *Nature* in 1987. To come up with their age estimate, the researchers compared the variations in mitochondrial DNA and then calculated how long it must have taken for so many mutations to build up in different lineages. Their estimate of 200,000 years was shockingly recent. It was already clear from the fossil record that human relatives lived in Europe and Asia at that time; now Wilson's work suggested that when ancestors of living humans migrated out of Africa, these other humans—with their own, different mitochondria—went extinct.

As it turned out, Wilson's statistics weren't as sound as he had believed, but later studies on mitochondria have come to essentially the same conclusions. Wilson worked only with fragments adding up to about 9 percent of the mitochondrial genome; in the December 7, 2000, issue of *Nature,* Swedish and German scientists reported on the results from examining all the mitochondrial genes—the entire sequence of about 16,000 base pairs. Comparing the sequences of fifty-three individuals, these researchers, too, found that their genes had come from an African woman. But instead of living 200,000 years ago, they estimated, she lived 170,000 years ago.

Newspaper reports on Wilson's 1987 paper dubbed this African woman "mitochondrial Eve." But despite the biblical overtones, she was not

the sole female progenitor of all living humans. She was simply the most recent female ancestor to whom we can all trace this particular genealogical connection. Mitochondrial Eve existed alongside thousands of other women in Africa, all of whom had mitochondrial genes of their own. Many of those other women had children who inherited their genes, and some of their descendants had children with mitochondrial Eve's descendants. But over the course of thousands of years, the other mitochondrial lineages gradually disappeared. A lineage would have vanished if the women carrying it died without having children or gave birth only to sons. As these different mitochondrial genes were dropping out, Eve's were becoming more widespread.

The way her genes came to dominate our species is similar to the way in which a patrilineal surname can take over an entire community. In a village where many different family names were in use thousands of years ago, everyone alive now could conceivably share just one. The fact that everyone in the village is named Chen, however, doesn't mean that one man named Chen was their sole male progenitor. Similarly, we descend from thousands of other women who were alive at the same time as mitochondrial Eve. We just don't carry their mitochondrial genes.

Just as mitochondrial genes contain a record of female lineages, men have a set of genes that can tell a story about the other half of our species. Of the twenty-three pairs of chromosomes carried by men in the nucleus of their cells, twenty-two consist of partners identical in length, shape, and sequence of genes. The remaining pair is different. From his father, a boy inherits a chromosome called Y, and from his mother, a chromosome called X. During the formation of sperm, as the other chromosomes shuffle their genes, only a small section of the Y chromosome exchanges bits of material with its partner. Most of it remains aloof, providing a clean, unmuddled pedigree passed down from father to son—a male counterpart to mitochondrial DNA.

The story embedded in the Y chromosome has been much harder to extract than that of mitochondrial DNA. The mitochondrial genome is small, only 16,000 base pairs long, making it easy to sequence, and every human cell contains an average of 1,700 mitochondria, offering plenty of targets for genetic probes. By contrast, each of a man's cells contains a single Y chromosome, and it is big, measuring 60 million base pairs long. Searching for markers on the Y chromosome is like looking for a few typos in a thirty-volume encyclopedia. By 1994, scientists had managed to find a grand total of only two markers on the Y.

Perhaps it was common 59,000 years ago for just a few men in each band to earn the privilege of fathering children.

The Y chromosome has finally been tamed by investigators at the laboratory of Stanford University geneticist L. Luca Cavalli-Sforza. In 1995 Stanford researchers Peter Underhill and Peter Oefner found a way to speed-read through the Y-chromosome encyclopedia. Soon they and their colleagues were discovering a new mutation every month or so (they're now up to 167). It was then relatively easy for them to study Y chromosomes from various parts of the world to see if they shared any particular mutation. If they did, it would mark them as descendants of a common ancestor.

Like Wilson's group, the Stanford team has used their markers to draw an evolutionary tree of the human race, and they find that the oldest branches are exclusively African, confirming that Africa is the motherland of us all. Some Africans spread out to the other continents, a journey that the Y chromosome records in exquisite detail. It reveals individual waves of migration from Asia to Europe, from Asia to Polynesia, and from Asia to the New World.

But there's one important disparity between the findings based on the Y chromosome and those based on mitochondrial DNA. Underhill and his colleagues established a clock for the Y chromosome, and in the November 2000 issue of *Nature Genetics* they estimated that Y-chromosome Adam, the man from whom all living men descend, lived only 59,000 years ago.

How can we all descend from two people who lived thousands of generations apart? These scientists are calculating the antiquity of the various genes we share, not attempting to reconstruct the complete family tree of the people who carry them. Only our mitochondrial genes descend from a common female ancestor who lived 170,000 years ago, and only our Y chromosomes descend from a single Y chromosome dating back 59,000 years.

The men who were alive in mitochondrial Eve's day carried a number of different versions of the Y chromosome. They passed their chromosomes down to their sons, and over time, each version of Y went through its own ups and downs. Finally, about 59,000 years ago, a man was born with a newly mutated Y chromosome that would eventually dominate our entire species. Other versions of the Y gradually disappeared as men died without children or had only daughters.

It's intriguing that Y-chromosome Adam appears to have lived so much later than mitochondrial Eve. His Y chromosome apparently needed less time to overwhelm the human gene pool. One possible explanation for this speed is that one of the genes on Adam's Y chromosome had a mutation that gave it an evolutionary edge, and natural selection then drove its spread. But natural selection of a gene is not the only force capable of making it more widespread—culture might have been responsible. Perhaps it was common 59,000 years ago for only a few men in each band to earn the privilege of fathering children. If that was the case, Y-chromosome lineages might have gone extinct quickly, because most men would have been unable to pass on their genes. The Stanford team is now exploring these two possible explanations.

The findings from research on the Y chromosome and mitochondrial DNA are only a taste of the genealogical feast that will be served up in the next few years. Last year, government and private-sector scientists made a joint announcement that they had sequenced the entire human genome. Researchers will now be able to find markers far more quickly—and not just on the Y chromosome or on mitochondrial DNA but on any gene they want to study. Some of these genes will turn out to be hundreds of thousands of years old. Others will turn out to be much younger, having evolved in response to recent epidemics or similar challenges.

All this new research makes me think differently about our child. We are not simply giving him or her my nose or my wife's eyes. We are giving our child tens of thousands of histories combined into a single genome. And she or he will carry this record of human existence another generation into the future. Somehow, the mysteries of swaddling don't seem like such a big deal anymore. □

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CELESTIAL EVENTS

Lost in Space

What goes up must come down. Or not.

By Richard Panek

Every sky watcher knows that what's "up" in our nighttime skies isn't up at all. Celestial objects may look as though they're "up there" to observers "down here" on Earth, but we long ago adjusted our thinking and accepted that they're simply moving across the vast reaches of empty space, where directions like up and down have no meaning. And for the most part, that's true.

The exception is what we ourselves have sent up—for example, the International Space Station (ISS), now under construction in orbit. But artificial satellites such as the ISS won't stay up there forever, and one reminder of this basic fact of physics is the impending return of the *Mir* spacecraft to our blue planet.

If all goes according to plan (never a safe bet when it comes to space missions), *Mir* should be reentering Earth's atmosphere between February 26 and 28, or about a week after this issue of *Natural History* comes off the presses. Much of *Mir* should disintegrate on reentry; any remaining pieces should land in the Pacific Ocean, off the coast of Australia. That crash-and-burn will reduce the number of man-made objects in the heavens by one, but the total will still be nearly 8,000, and growing almost daily.

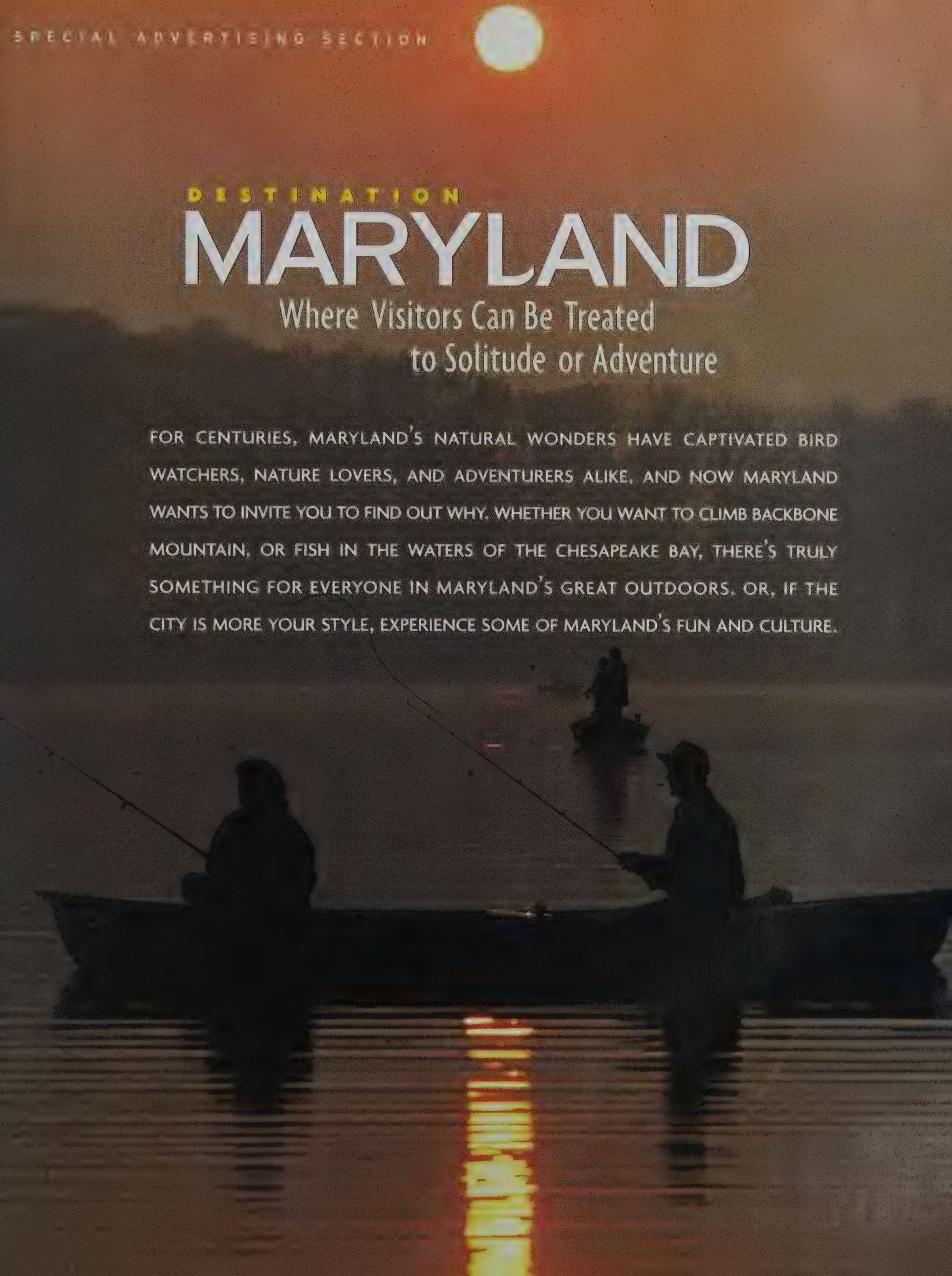
About 2,500 of those objects are genuine satellites—spacecraft specifically designed to orbit Earth. As for the other 5,000 or so out there, they're the celestial equivalent of roadside trash: hatch covers, rocket bodies, bits and pieces of payloads that have disintegrated or (at the rate of about six a year) unexpectedly exploded, even a glove that a *Gemini* astronaut lost back in the 1960s. And then there's the celestial equivalent of a roadside attraction: a one-third-sized working model of the *Sputnik 1* satellite, released by *Mir* cosmonauts in 1997 on the fortieth anniversary of the launch that initiated the space age.

NASA/JOHNSON SPACE CENTER

Working satellites make up about 5 percent of Earth's closely orbiting space debris (white dots). The other 95 percent includes everything from nuclear reactors to a toothbrush.

Is anybody keeping track of all this stuff? Fortunately, yes: the U.S. Space Command's Space Control Center (SCC) near Colorado Springs, Colorado. The SCC continuously monitors the location of each object, not only to distinguish between friend and foe, but to facilitate navigation by determining what could potentially be in the way. When the bankrupt global satellite telephone company Iridium LLC needed to think about dumping

(Please turn to page 43)



DESTINATION

MARYLAND

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COME OUT AND PLAY

The wonderful thing about Maryland is that everything is within a 3-hour drive of its biggest city, Baltimore. That's why the state's tourism motto is *So many things to do. So close together.*

CENTRAL MARYLAND

IF SOLITUDE IS WHAT YOU ARE LOOKING FOR, visit Yachts Unlimited, located at Great Oak Landing Marina on Fairlee Creek. Yachts Unlimited offers you the unique opportunity to charter beautiful yachts. Rent a bike in Ashland or Monkton, because just an hour's drive from Baltimore you'll find the 40-mile Northern Central Rail Trail which winds through the countryside on its way to the Mason-Dixon line and beyond. Before you begin your trip, stop by your local book store and pick up some travel books covering the Chesapeake Bay area. Johns Hopkins University Press is a good place to start. Popular destinations in this region include Annapolis, Baltimore City, Columbia, Havre de Grace, Towson, Westminster, Ellicott City and Bel Air.

EXPLORE ONE OF THE EAST'S LAST REMAINING UNSPOILED WILDERNESSES.

WESTERN MARYLAND

WITHIN THE MOUNTAINS OF WESTERN MARYLAND, adventure and natural beauty come together to help you enjoy a fun-filled weekend. If there's a touch of Roy Chapman Andrews in you, but you want to stay a little closer to home, then this is the perfect place for your next expedition. Experience the region's world-class trout fishing with one of the local guides along the Upper Youghiogheny River. Novice fishermen can take advantage of the Yough's gentler sections or the dramatic canyons of the Potomac's North Branch. Accomplished anglers can move to the heart of the action in the Savage River, a tailwater fishery and catch-and-release trophy area. At the end of your day, you can gaze upon the stars while camping at Garrett County's Big Run State Park in the heart of the Savage River State Forest. Western Maryland's most popular destinations include Antietam, Cumberland, Deep Creek Lake, the C&O Canal Park and Hagerstown.

CAPITAL REGION

THE CAPITAL REGION OF FREDERICK, MONTGOMERY, and Prince George Counties is home to some wonderful state parks that offer everything from hiking to biking. Cunningham Falls State Park, 15 miles north of Frederick, in the Catoctin Mountains, is the home of the breathtakingly beautiful Cunningham Falls. This 78-foot cascading waterfall roars through a rocky gorge and a lake. If you want to take in some history, the Capital Region is the place to do it. A crucial Civil War battle was fought in Frederick County on July 9, 1864. At Monocacy National Battlefield, walk in the footsteps of a small Union force of 5,800 men who managed to stall the advance of an 18,000-strong Confederate army for a full day. This battle prevented an invasion of the nation's capital. Popular destinations in this region include Frederick, Bethesda, College Park, Gaithersburg, Laurel, Rockville, Thurmont and Upper Marlboro.

DESTINATION MARYLAND

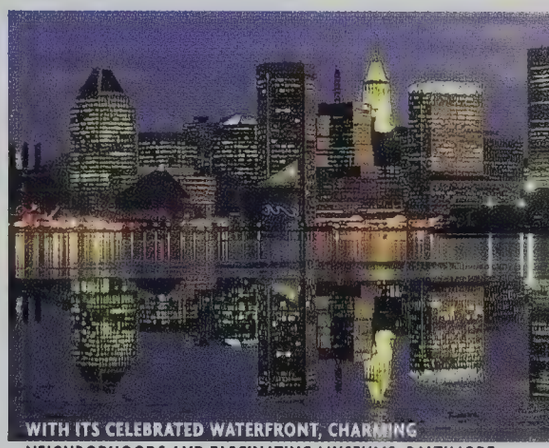
Maryland's 47 state parks, six forests and state public lands encompass more than 372,000 public acres.

SOUTHERN MARYLAND

Miles of magnificent shoreline along the Potomac River and rural scenery offer another treat in this diverse state. Explore the 288-acre Great Blue Heron Sanctuary, protected by the Nature Conservancy on the tranquil Nanjemoy Creek. There you can experience an amazing feat of nature as more than 1,100 breeding pairs of great blue herons return to this site each winter to mate and bear their young. Paddle up the Port Tobacco River, just south of the Nanjemoy, with a stop at Chapel Point State Park. Here you can hike to a scenic overlook for an impressive view of the river and St. Ignatius Church, which served as a stop on the Underground Railroad. Popular destinations include Calvert Cliffs, LaPlata, Leonardtown, Prince Frederick, Solomons, historic St. Mary's City and Waldorf.

EASTERN SHORE

The Eastern Shore of Maryland offers rolling hills, scenic shores and quaint towns—the recipe for a perfect weekend adventure. Begin your journey at Janes Island State Park. Easy paddling along 30 miles of marked water trails takes you through a 2,900-acre salt marsh that is abundant with wildlife—snowy egrets, diamond-back terrapins and herons, along with bluefish, rockfish, sea trout and flounder. The Eastern Shore is known for its mix of scenery and hospitality and is a seafood lover's paradise. Stop by one of the waterside restaurants and have a Maryland shore dinner. Popular destinations include Cambridge, Centerville, Chestertown, Crisfield, Denton, Easton, Fair Hill, Kent Narrows, Ocean City, Pokomoke City, Princess Anne, Rock Hall, Smith Island, Snow Hill, St. Michaels and surrounding towns. ❐



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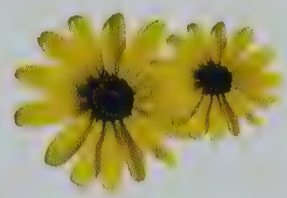
MARYLAND'S UNIQUE COUNTIES

WORCESTER COUNTY
The Wild Ponies of Assateague

When you come to Maryland, you certainly don't want to miss Assateague Island State Park and National Seashore, home to the famed wild ponies and so much more. Assateague is an uninhabited island running parallel to the shoreline with 37 mile of dunes, marshlands, and beaches. You'll be able to camp, fish, canoe, kayak, hike, or bike along paths that provide a glimpse of the ponies, waterfowl and other wildlife.



There's so much history to discover in Maryland and so much nature to admire.

Western Worcester provides visitors with its own type of outdoor adventure. The Pocomoke River State Forest and Park covers more than 13,000 acres of cypress swamps and loblolly pines. The river and its shoreline provided cover for escaped slaves traveling the Underground Railroad to the North. The Pocomoke River flows through one of the northernmost cypress swamps in the country. More than 27 species of mammals, 29 species of reptiles, 14 species of amphibians, and 172 species of birds have been seen in the wetlands that border the Pocomoke.

Of course Worcester has its share of history too. Visit the Mt. Zion One-Room School Museum and the Julia A. Purnell Museum in Snow Hill to get a glimpse of life from the pre-colonial days to the late 19th century. A walking-tour of Snow Hill offers some interesting historical details about eight churches and 52 homes.

FREDERICK COUNTY
History's Crossroads

The National Road, the first federally funded highway in the United States, follows a trail used by George Washington as a route to link the port of Baltimore with the interior of the United States. The National Road travels through the heart of Frederick, Maryland's historic district. This is where settlers bound for the wilderness began their journeys, and the winds of war brought Union and Confederate troops together in battle twice.

Discover even more history with a visit to the National Museum of Civil War Medicine. Telling the medical story of the Civil War, the museum gives visitors a glimpse of the care and healing, courage and devotion of caregivers and patients on both sides of the war.

And then stop at two well-preserved Civil War battle fields where critical battles took place: the Battle of Monocacy and the engagement at South Mountain.

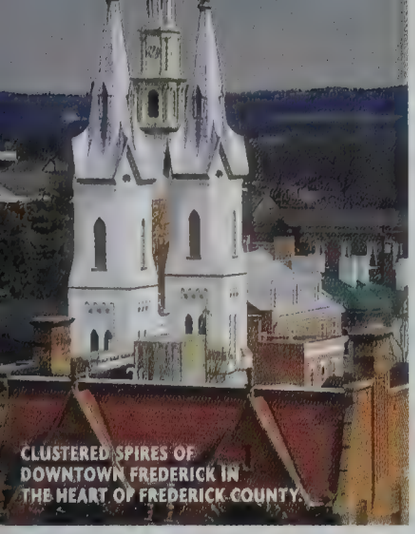
Before you leave downtown Frederick, don't miss the shops, restaurants and theaters that make these streets so special. You'll want to see each and every one of the trompe l'oeil murals decorating walls and bridges. The work of local artist William Cochran, the murals have become a symbol of Frederick's unique character.

ST. MARY'S COUNTY
A Bit of America's Storied Past

Historic St. Mary's City is the site of the state's first capital and now one the finest 17th century tourist attraction in North America. St. Mary's City boasts a stunning 800-acre outdoor history museum along the banks of the St. Mary's River. See a replica of the square-rigged *Dove*, one of the two ships that brought English settlers to the state in 1634. Before choosing St. Mary's City, the early settlers first landed at St. Clements Island, now a state park accessible by water-taxi. There you'll find a wonderful museum devoted

AT FORT McHENRY, FRANCIS SCOTT KEY WAS INSPIRED TO WRITE "THE STAR SPANGLED BANNER" AFTER THE SUCCESSFUL DEFENSE AGAINST THE BRITISH DURING THE WAR OF 1812.

DESTINATION MARYLAND


CLUSTERED SPIRES OF DOWNTOWN FREDERICK IN THE HEART OF FREDERICK COUNTY.

to the island's history and importance.

Not too far away, on Piney Point you can take a picnic lunch and visit the Piney Point Lighthouse Museum and Park. The lighthouse, built in 1836, was the first permanent lighthouse built on the Potomac River and is the only remaining accessible lighthouse on its original location in Southern Maryland. The museum tells the story of a U-1105 German Submarine from WWII, which is on display. After the war, the Navy acquired ownership of the submarine and it was eventually scuttled off the coast of Piney Point. In November of 1994, the wreck was designated as Maryland's first historic shipwreck preserve.

Nature lovers will find more than 400 miles of shoreline to explore in St. Mary's County. To find more out about the region, take a sail aboard one of the several historic vessels in the area that offer scenic cruises or sails.

CALVERT COUNTY

Celebrate the Culture of the Chesapeake

A hike through Calvert Cliffs State Park brings you to the majestic Calvert Cliffs on the Chesapeake Bay. Formed over 15 million years ago, the cliffs contain more than 600 species of fossils. The park is ideal for hiking and walking, picnicking, fishing, and fossil hunting, and there is a 45-minute walk one-way (two miles) to the beach. The area under the cliffs is closed due to landslide activity, but fossil collecting can be done along the open beach where there are no cliffs.

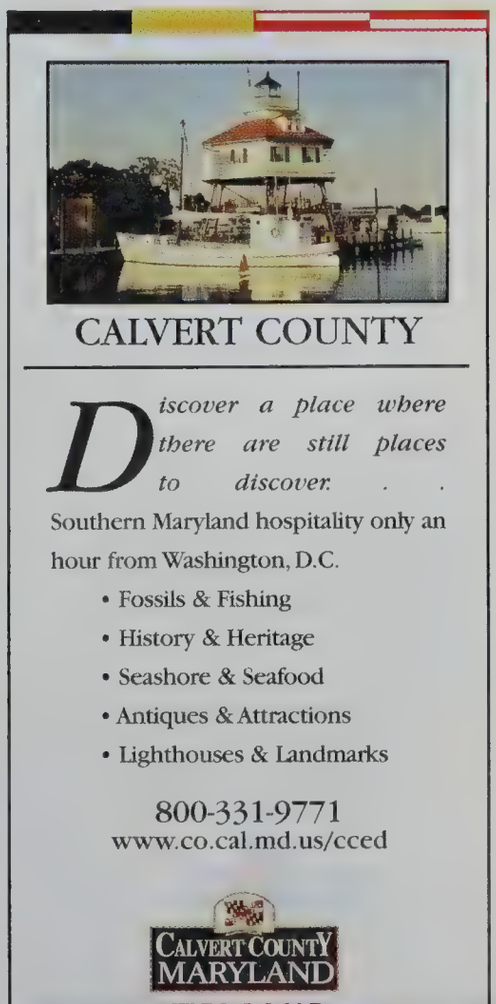
In Calvert County, you can also take advantage of some wonderful ecological spots. The Battle Creek Cypress Swamp Sanctuary protects the country's northernmost naturally occurring stand of bald cypress. A boardwalk at Flag Ponds Nature Park leads through delicate wetlands. Three different scientific centers—the Academy of Natural Sciences' Estuarine Research Center, the American Chestnut Land Trust, and the Chesapeake Biological Laboratory—offer an introduction to this diverse and unique environment.

The rich maritime history and diversity of life found in the Chesapeake Bay come alive at the Calvert Marine Museum. Here you'll find boats, models, paintings, woodcarvings, aquariums and fossils. Outdoor exhibits include a boat basin, river otter habitat, and a re-created salt marsh. Enjoy a leisurely one-hour cruise around Solomons Harbor and the Patuxent River aboard the *Wm. B. Tennison*, the oldest Coast Guard licensed passenger-carrying vessel on the Chesapeake. Built in 1899, this nine-log chunk-built bugeye was later converted from sail to power, serving as an oyster buyboat. After your cruise, sample the fresh catches served at Solomon's excellent restaurants.

CHARLES COUNTY

Southern Maryland's Hidden Gem

Charles County is a destination that combines history, the outdoors, culture and fabulous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CALVERT COUNTY MARYLAND
WELCOME

seafood into one unforgettable weekend. Explore the fossil hunting grounds of Purse State Park, or take in the forests and wetlands of the Mattawoman Natural Environment Area.

If you like history, you'll be intrigued by the small town of Benedict, the only spot in the United States where foreign troops have invaded our shores. The British army landed here on their way to Washington D.C. during the war of 1812. Two of the troops are buried at Old Fields Chapel Cemetery in Hughesville.

For a bit of exercise, you can take a 24-mile bike ride through history, following the trail of John Wilkes Booth. Your tour picks up his trail at the home of Samuel Mudd, the doctor who set Booth's leg before he continued his escape into Virginia. The route follows lightly traveled roads through rolling countryside and scenic farmland. Stop at the St. Mary's Catholic Church, built in 1848, where Dr. Mudd is buried. You will peddle around the Zekiah Swamp and end up in Pope's Creek on the Potomac River. Here, you can enjoy a Maryland crab dinner without any guilt.

After taking a vacation in Maryland, you will definitely understand why they say *So many things to do. So close together.* For more information about this extraordinary state, call 1-877-333-4455 to speak to a Maryland travel specialist. ❐

This special editorial/advertising supplement was created by the Natural History Special Sections Department and did not involve the magazine's editorial staff. **WRITER:** Stephanie Fekety
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DESTINATION
MARYLAND

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(Continued from page 36)
its sixty-six satellites last year, it asked the SCC for guidance in steering its suddenly useless inventory safely to oblivion. (The Pentagon later decided to keep the satellites aloft for at least two more years.)

Many of us who were alive in the 1960s have memories of standing outside at night, straining for a glimpse of Telstar or some other primitive satellite as it slowly traveled across the backdrop of the so-called fixed stars. Whatever romantic visions of space exploration were inspired by that sight have long ago receded into collective nostalgia. But sky watchers can still get some kind of existential thrill from locating celestial objects that, unlike the Moon, planets, and stars, will probably vanish from the universe before they do.

Only a small proportion of orbiting objects are visible through even the most powerful backyard telescopes, but the recent addition of the ISS to the night sky now gives naked-eye observers something to see. It can reach the brightness of a first-magnitude star if it catches the light of the Sun just right. As the station itself grows, that radiance will also grow. To find out precisely when and in what part of the sky the space station is visible, you can visit spaceflight.nasa.gov/realdata/sightings/, which links to sighting opportunities for more than 200 locations worldwide.

As for *Mir,* it may be going but it's not gone yet. And until it is, you can determine the spacecraft's availability and visibility by checking a Web site established by *Sky & Telescope* magazine at www.skypub.com/sights/satellites/mir.shtml.

And then there's the *Gemini* glove. No, you can't see it, but surely it, too, deserves a dedicated Web site to inform us of its whereabouts. Forget the beeping *Sputnik 1* model. That glove is a more touching monument to the space age—a humble reminder that at any time, and despite all our technological wizardry, our reach can still exceed our grasp.

Richard Panek is author of Seeing and Believing: How the Telescope Opened Our Eyes and Minds to the Heavens *(Penguin, 1999).*

THE SKY IN MARCH

By Joe Rao

Mercury hugs the southeastern horizon before dawn in early March. Despite being far from the Sun (27.5° at greatest elongation on the 11th), it comes into view only for those willing to search diligently with binoculars.

Venus is the blazing evening "star" shining in the west at dusk for most of the month. On the 1st, Venus stands so high that it remains visible for three hours after sunset. By the 27th, however, it sets only about half an hour after sundown. During March, the planet swings closer to Earth and grows to an apparent diameter nearly 1/30 that of a full Moon. Venus's crescent is visible in telescopes, binoculars, and maybe with the naked eye. But the crescent also thins throughout the month, so its magnitude fades from -4.6 to -3.8. Its illuminated fraction narrows to a hairline one percent by March 27. Apparitions of Venus go through an eight-year cycle, so its appearance in 2001 closely duplicates that in 1993. At only one point in the cycle do those in the Northern Hemisphere get a chance to see Venus at both dusk and dawn within twenty-four hours, and March brings us this rare opportunity. The best chance to see Venus as both the evening and the morning "star" is immediately after sunset on the 27th and then just before sunrise the next morning; look for it very low on the eastern horizon.

Mars rises within an hour of midnight local time in March. As it continues to approach Earth, its brightness noticeably increases, from magnitude +0.5 on the 1st to -0.2 by month's end. On the night of March 2–3, it passes about 5° north of the first-magnitude star Antares, the "rival of Mars," though the planet will appear to shine nearly twice as bright.

Jupiter and Saturn continue to be prominent in the evening sky. Coming into view high in the southwest, Jupiter (in the constellation Taurus) is, next to Venus, by far the brightest "star" of the night. During early twilight, it lies about 30° to 40° above and to the left of Venus. Yellow Saturn and the red first-magnitude star Aldebaran (also in Taurus) soon emerge, flanking Jupiter in the deepening dark-blue sky. Use your binoculars for observing the Taurus get-together: even the most ordinary pair will show dozens of the Pleiades' and Hyades' stars and at least one of Jupiter's four bright moons. As evening progresses, the whole assemblage wheels lower in the west, setting by midnight.

The Moon is at first quarter on March 2 at 9:03 P.M. The full Moon comes on March 9 at 12:23 P.M., last quarter on the 16th at 3:45 P.M., and the new Moon on the 24th at 8:21 P.M.

The vernal equinox occurs at 8:31 A.M. on March 20. Spring begins in the Northern Hemisphere, fall in the Southern Hemisphere.

Unless otherwise noted, all times are given in Eastern Standard Time.

BIOMECHANICS

The Fine Art

As it rocks from side to side, a walking penguin may look clumsy, but its movements are actually quite efficient.

Story by Carl Zimmer ~ Illustration by Sally J. Bensusen

When Tim Griffin and Rodger Kram set out to study how penguins walk, they didn't expect to be impressed. Compared with long-legged ostriches striding across a plain, waddling penguins come up short. Underwater they may be able to race like torpedoes in tuxedos, but on land they are more apt to evoke laughter than to inspire respect.

Previous research on penguins seemed to back up the laughter with hard numbers. Pound for pound, a penguin on land uses twice as much energy as other animals of its size to walk a given distance. Scientists laid the blame for this expense on waddling, the (presumably) energetically costly business of the bird's throwing its body first to one side and then to the other as it walks.

Griffin and Kram, both at the University of California, Berkeley, decided to test the assumption by measuring the work involved in waddling. So they filmed emperor penguins walking over a force-sensitive plate. Their data enabled them to calculate not just the force of each step but also the direction in which the force was acting and how fast the penguins were moving.

Similar studies on humans and other land animals have shown that walking is a surprisingly efficient way to move. Planting a foot in front of your body as you walk forward, you rise up slightly. Once your body is positioned directly above the foot, you start to fall forward and downward. In this process, much of the kinetic energy of your forward movement is turned into gravitational energy, which is then transformed into moving forward again. The same process occurs when a pendulum converts the energy it derives from moving side to side into moving upward against gravity. A walking person is like a pendulum turned upside down. Taking advantage of gravity this way saves lots of energy. Experiments have shown, for example, that a person's muscles need to supply only 35 percent of the work they would have to perform if there were no inverted pendulum involved. As the walker "falls" with each step, the muscles manage to recover 65 percent of the energy they put into a stride.

Griffin and Kram were amazed to discover that in this respect the penguins were actually superior to humans, recovering up to 80 percent of the energy they put into each step—among the highest rates ever recorded for any animal. How is this possible? Penguins not only rise and fall along the line in which they are walking (as we do); they also swing their bodies from side to side like pendulums. This side-to-side waddling provides additional energy for fighting gravity.

Waddling is not wasteful. The emperor penguin reuses some energy from one sway to make the next one.

Energy from this sideways movement helps the penguin reach an upright position when only one leg is on the ground. As the bird swings back—or rather, falls—to the opposite side, it uses gravitational energy both to move sideways and to step forward.

Biologists have given waddling a bad rap, suggest Griffin and Kram. Penguins do pay a steep price to walk, but the researchers claim that waddling is not to blame. Instead, they propose, the trouble comes from having such short legs. Long-legged animals with longer strides maintain contact with the ground for more time during each step than do short-legged creatures. This allows a long-legged creature to use slower-working, more efficient muscle fibers. An emperor penguin is a hefty bird, weighing about forty pounds—in the same range as the flightless South American rhea, which is similar to an ostrich. But the emperor's legs are only one-third the length of the rhea's, or only about as long as those of the guinea fowl, a bird weighing only three pounds. Moving a rhea's body around on a guinea fowl's legs, a penguin has no choice but to use a lot of energy.

Like many animals, penguins are caught in a biomechanical bind. With their flipperlike wings, they are well adapted for swimming, and their short legs may help reduce drag underwater. But because they're birds and not fish, penguins cannot completely give up life on land, where they find mates, lay their eggs, and raise their chicks. Emperors are, in fact, champion walkers, traversing up to 150 miles of frozen sea ice to reach their winter rookeries. Far from wasting energy, waddling may help keep a penguin alive. □

# of Waddling

The Scavenging of "Peking Man"

New evidence shows that a venerable cave was neither hearth nor home.

By Noel T. Boaz and Russell L. Ciochon

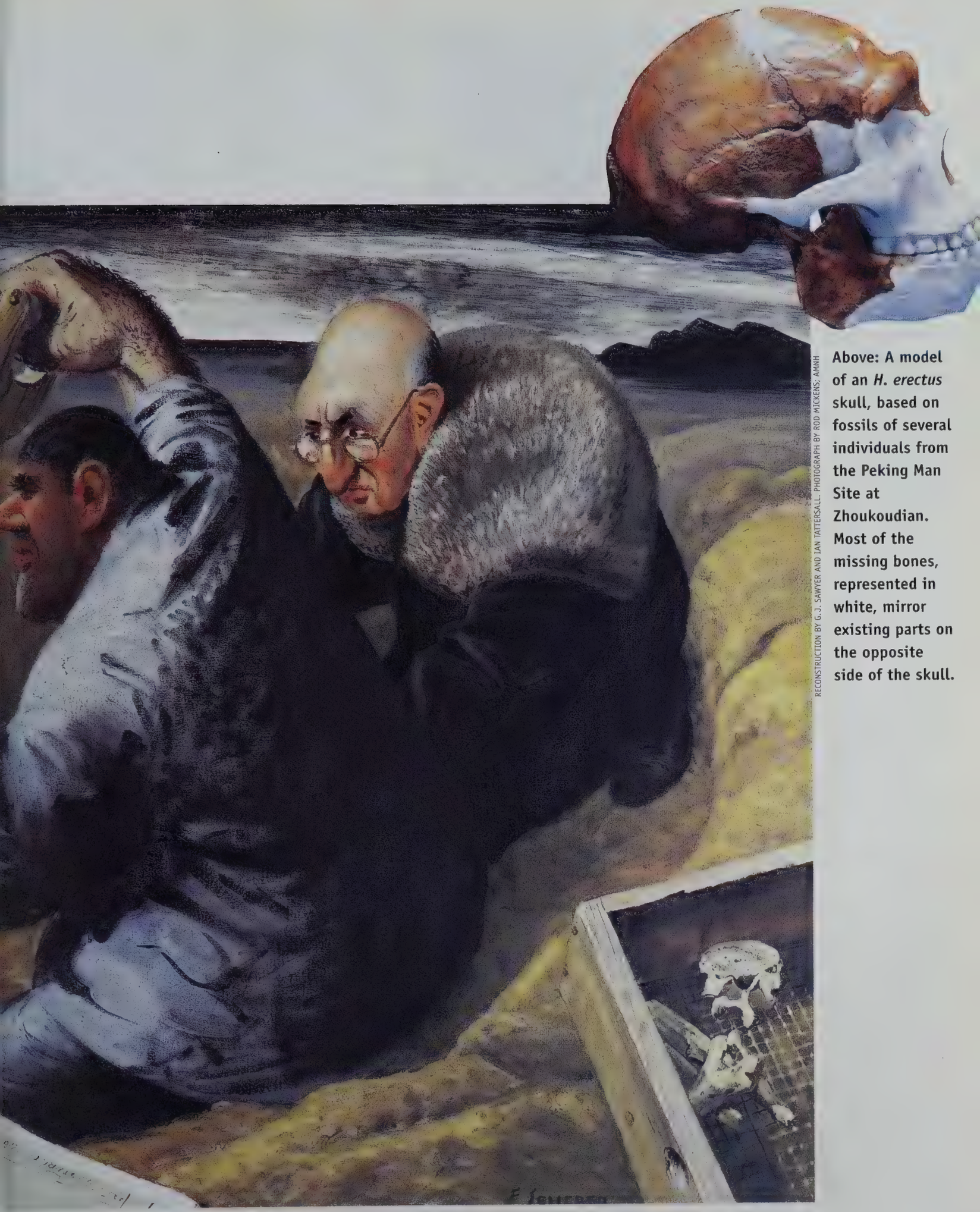
PAINTING BY FRED F. SCHERER, JACKIE BECKETT; AMNH

Franz Weidenreich, who in the 1930s studied the fossils of *Homo erectus* unearthed in China, is caricatured along with Ralph von Koenigswald (wielding the shovel), who found fossils of *H. erectus* in Java. The fanciful setting is, according to the artist, "any place where the dead are disturbed."

China is filled with archaeological wonders, but few can rival the Peking Man Site at Zhoukoudian, which has been inscribed on UNESCO's World Heritage List. Located about thirty miles southwest of Beijing, the town of Zhoukoudian boasts several attractions, including ruins of Buddhist monasteries dating from the Ming Dynasty (1368–1644). But the town's main claim to fame is Longgushan, or Dragon Bone Hill, the site of the cave that yielded the first (and still the largest) cache of fossils of *Homo erectus pekinensis,* historically known as Peking man—a human relative who walked upright and whose thick skull bones and beetling brow housed a brain three-quarters the size of *H. sapiens*'s.

The remains of about forty-five individuals—more than half of them women and children—along with thousands of stone stools, debris from tool manufacturing, and thousands of animal bones, were contained within the hundred-foot-thick deposits that once completely filled the original cave. The task of excavation, initiated in 1921, was not completed until 1982. Some evidence unearthed at the site suggested that these creatures, who lived from about 600,000 to 300,000 years ago, had mastered the use of fire and practiced cannibalism. But despite years of excavation and analysis, little is certain about what occurred here long ago. In the past two years we have visited the cave site, reexamined the fossils, and carried out new tests in an effort to sort out the facts.

To most of the early excavators, such as



RECONSTRUCTION BY G.J. SAWYER AND IAN TATTERSALL. PHOTOGRAPH BY ROD MICKENS; AMNH

Above: A model of an *H. erectus* skull, based on fossils of several individuals from the Peking Man Site at Zhoukoudian. Most of the missing bones, represented in white, mirror existing parts on the opposite side of the skull.

AMNH

The early investigations at Zhoukoudian were coordinated by the Cenozoic Research Laboratory in Beijing. Staff members there included (left to right in foreground) Teilhard de Chardin, Franz Weidenreich, Yang Zhongjian, Pei Wenzhong, and Bian Meinian.

anatomist Davidson Black, paleontologist Pierre Teilhard de Chardin, and archaeologist Henri Breuil, the likely scenario was that these particular early humans lived in the cave where their bones and stone tools were found and that the animal bones were the remains of meals, proof of their hunting expertise. Excavation exposed ash in horizontal patches within the deposits or in vertical patches along the cave's walls; these looked very much like the residue of hearths built up over time.

A more sensational view, first advanced by Breuil in 1929, was that the cave contained evidence of cannibalism. If the animal bones at the site were leftovers from the cave dwellers' hunting forays, he argued, why not the human bones as well? And skulls were conspicuous among the remains, suggesting to him that these might be the trophies of headhunters. Perhaps, Breuil even proposed, the dull-witted *H. erectus* had been prey to a contemporary, advanced cousin, some ancestral form of *H. sapiens*. Most paleoanthropologists rejected this final twist, but the cannibalism hypothesis received considerable support.

In the late 1930s Franz Weidenreich, an eminent German paleoanthropologist working at Peking Union Medical College, described the *H. erectus* remains in scientific detail. A trained anatomist and medical doctor, he concluded that some of the skulls showed signs of trauma, including scars and fresh injuries from attacks with both blunt and sharp instruments, such as clubs and stone tools. Most convincing to him and others was the systematic destruction of the skulls, apparently at the hands of humans who had decapitated the victims and then broken open the skull bases to retrieve the brains. Weidenreich also believed that the large longitudinal splits seen, for example, in some of the thighbones could only have been caused by humans and were probably made in an effort to extract the marrow.

Others held dissenting views. Chinese paleoanthropologist Pei Wenzhong, who codirected the early Zhoukoudian excavations, disagreed with Breuil and suggested in 1929 that the skulls had been chewed by hyenas. Some Western scientists also had doubts. In 1939 German paleontologist Helmuth Zapfe published his findings on the way hyenas at the Vienna zoo fed on cow bones. Echoing Pei's earlier observations, of which he was aware, Zapfe convincingly argued that many of the bones found at sites like Longgushan closely resembled modern bones broken up by hyenas. In fact, a new term, taphonomy, was coined shortly thereafter for the field Zapfe pioneered: the study of how, after death, animal and plant remains become modified, moved, buried, and fossilized. Franz Weidenreich soon revised his prior interpretation of several *H. erectus* bones whose condition he had attributed to human cannibalistic activity, but he continued to argue that the long-bone splinters and broken skull bases must have resulted from human action.

Following disruptions in fieldwork during World War II (including the loss of all the *H. erectus* fossils collected at Longgushan up to that time, leaving only the casts that had been made of them), Chinese paleoanthropologists resumed investigation of the site. While rejecting the idea of cannibalism, they continued to look upon the cave as a shelter used by early humans equipped with stone tools and fire, as reflected in the title of paleoanthropologist Jia Lanpo's book *The Cave Home of Peking Man,* published in 1975.

About this time, Western scientists began to appreciate and develop the field of taphonomy. A few scholars, notably U.S. archaeologist Lewis R. Binford, then reexamined the Longgushan evidence, but only from a distance, concluding that the burning of accumulated bat or bird guano may have accounted for the ash in the cave. With the founding in 1993 of the Zhoukoudian International Paleoanthropological Research Center at Beijing's Institute of Vertebrate Paleontology and Paleoanthropology,

a new era of multidisciplinary and international research at Longgushan began. At the institute, we have been able to collaborate with paleontologists Xu Qinqi and Liu Jinyi and with other scholars in a reassessment of the excavations.

One of taphonomy's maxims is that the most common animals at a fossil site and/or the animals whose remains there are the most complete are most likely the ones to have inhabited the area in life. Standing in the Beijing institute amid row after row of museum cases filled with mammal fossils from the cave, we were immediately struck by how few belonged to *H. erectus*—perhaps only 0.5 percent. This suggests that most of the time, this species did not live in the cave. Furthermore, none of the *H. erectus* skeletons is complete. There is a dearth of limb bones, especially of forearms, hands, lower leg bones, and feet—indicating to us that these individuals died somewhere else and that their partial remains were subsequently brought to the cave. But how?

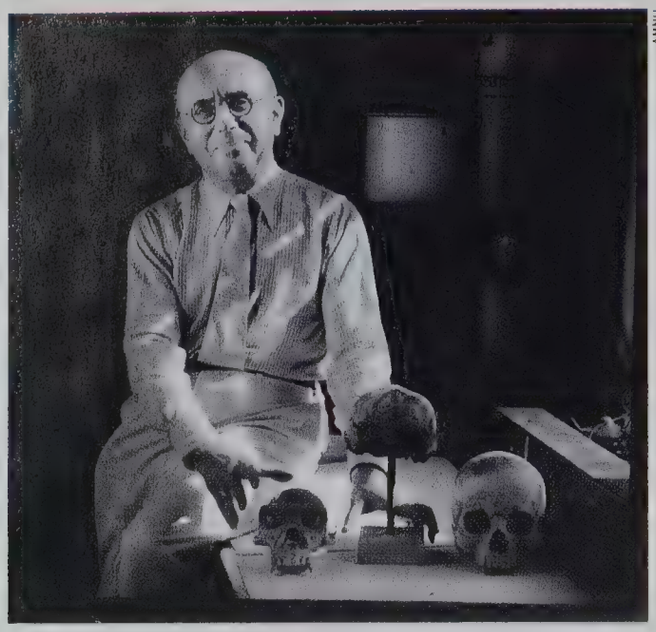
AMNH

During the 1930s, excavators dug down through the hundred-foot-thick deposits that contained the remains of "Peking man." The deposits, which also yielded animal bones, stone tools, and layers of ash, had completely filled an ancient cave.

The answer was suggested by the remains of the most common and complete animal skeletons in the cave deposit: those of the giant hyena, *Pachycrocuta brevirostris.* Had *H. erectus,* instead of being the mighty hunters of anthropological lore, simply met the same ignominious fate as the deer and other prey species in the cave? This possibility, which had been raised much earlier by Pei and Zapfe, drew backing from subsequent studies by others. In 1970, for example, British paleontologist Anthony J. Sutcliffe reported finding a modern hyena den in Kenya that contained a number of human bones, including skulls, which the animals had apparently obtained from a nearby hospital cemetery. In the same year, South African zoologist C. K. Brain published the findings of his extensive feeding experiments with captive carnivores, akin to those of Zapfe three decades earlier. One of Brain's conclusions was that carnivores tend to chew up and destroy the ends of the extremities, leaving, in the case of primates, very little of the hands and feet.

It looked as if H. erectus *had smashed open the skulls to cannibalize the brains.*

To test the giant hyena hypothesis, we examined all the fossil casts and the few actual fossils of *H. erectus* from Longgushan. We looked for both carnivore bite marks and the shallow, V-shaped straight cuts that would be left by stone tools (although we realized that cut marks would probably not be detectable on the casts). We also analyzed each sample's fracture patterns. Breaks at right angles indicate damage long after death, when the bone is fossilized or fossilizing; fractures in fresh bone tend to be irregular, following natural structural lines. Breakage due to crushing by cave rocks is usually massive, and



Franz Weidenreich at his laboratory at the American Museum of Natural History in the 1940s, with ape and human skulls

the fracture marks characteristically match rock fragments pushed into the bone.

We were surprised by our findings. Two-thirds of Longgushan's *H. erectus* fossils display what we are convinced are one or more of the following kinds of damage: puncture marks from a carnivore's large, pointed front teeth, most likely the canines of a hyena; long, scraping bite marks, typified by U-shaped grooves along the bone; and fracture patterns comparable to those created by modern hyenas when they chew bone. Moreover, we feel that

Two-thirds of the fossils show bite marks or fractures inflicted by carnivores.

the longitudinal splitting of large bones—a feature that Weidenreich considered evidence of human activity—can also be attributed to a hyena, especially one the size of the extinct *Pachycrocuta,* the largest hyena known, whose preferred prey was giant elk and woolly rhinoceros. One of the *H. erectus* bones, part of a femur, even reveals telltale surface etchings from stomach acid, indicating it was swallowed and then disgorged.

The pattern of damage on some of the skulls sheds light on how hyenas may have handled them. Bite marks on the brow ridge above the eyes indicate that this protrusion had been grasped and bitten by an animal in the course of chewing off the face. Most animals' facial bones are quite thin, and modern hyenas frequently attack or bite the face first; similarly, their ancient predecessors would likely have discovered this vulnerable region in *H. erectus*. Practically no such facial bones, whose structure is known to us from discoveries at other sites, have been found in the Longgushan cave.

The rest of the skull is a pretty tough nut to crack, however, even for *Pachycrocuta,* since it consists of bones half again as thick as those of a modern human, with massive mounds called tori above the eyes and ears and around the back of the skull. Puncture marks and elongated bite marks around the skulls reveal that the hyenas gnawed at and grappled with them, probably in an effort to crack open the cranium and consume the tasty, lipid-rich brain. We concluded that the hyenas probably succeeded best by chewing through the face, gaining a purchase on the bone surrounding the foramen magnum (the opening in the cranium where the spinal cord enters), and then gnawing away until the skull vault cracked apart or the opening was large enough to expose the brain. This is how we believe the skull bases were destroyed—not by the actions of cannibalistic *H. erectus*.

We know from geological studies of the cave that the animal bones found there could not have been washed in by rains or carried in by streams: the sediments in which the bones are found are either very fine-grained—indicating gradual deposition by wind or slow-moving water—or they contain angular, sharp-edged shards that would not have survived in a stream or flood. Some of the bones may have belonged to animals that died inside the cave during the course of living in it or frequenting it. Other bones were probably brought in and chewed on by hyenas and other carnivores.

Cut marks we observed on several mammal bones from the cave suggest that early humans did sometimes make use of Longgushan, even if they were not responsible for accumulating most of the bones. Stone tools left near the cave entrance also attest to their presence. Given its long history, the cave may have served a variety of occupants or at times have been configured as several separate, smaller shelters. Another possibility is that, in a form of time-sharing, early humans ventured partway into the cave during the day to scavenge on what the hyenas had not eaten and to find temporary shelter. They may not have realized that the animals, which roamed at twilight and at night, were sleeping in the dark recesses a couple of hundred feet away.

What about the ash in the cave, which has been taken as evidence that *H. erectus* used fire? Recently published work by geochemist Steve Weiner and

his team at the Weizmann Institute of Science in Israel suggests that the fires were not from hearths. In detailed studies of the ash levels, they discovered no silica-rich layers, which would be left by the burning of wood. Wood (as well as grass and leaves) contains silica particles known as phytoliths—heat-resistant residues that are ubiquitous in archaeological hearth sites. The results indicate that fire was present in the cave but that its controlled use in hearths was not part of the story.

Still, a human hand may somehow be implicated in these fires. One possibility we are exploring in the next phase of our research is that Longgushan was a place where *Pachycrocuta* and *H. erectus* confronted each other as the early humans sought to snatch some of the meat brought back to the cave by the large hyenas. *Pachycrocuta* would have had the home court advantage, but *H. erectus,* perhaps using fire to hold the carnivore at bay, could have quickly sliced off slivers of meat. Although today we might turn up our noses at such carrion, it may have been a dependable and highly prized source of food during the Ice Age. □

RUSSELL L. CIOCHON

A composite image of the skulls of *Pachycrocuta* and *H. erectus,* left, shows how the giant hyena may have attacked the face. Beneath is a disgorged piece of an *H. erectus* thighbone. Below: An artist's depiction of the cave shows hyenas consuming the remains of an *H. erectus.*

WILL THOMSON

A WORLD AP

The larval lifestyle may seem alien to us terrestrial bipeds, but it comes quite naturally to most creatures—especially inhabitants of the world's oceans.

By Gregory A. Wray

A tiny larva, not much larger than a speck of dust, swims through the swirling soup of plankton in the cool waters of Puget Sound. Rows of minute cilia along the sides of its body pulsate continuously, pulling single-celled algae near before flicking them into its mouth. Fifty feet below the larva, an adult of the same species creeps across the rocky seafloor in search of a meal. Looking nothing like the larva and colossal by comparison (weighing about a million times more), this animal—a *Pisaster ochraceus* sea star, or starfish—is an active predator, searching out clams and mussels to pry open with its powerful arms. The larva and the adult lead lives that differ in almost every conceivable way: what they eat, how they move, what predators they must avoid, and the physical world they must negotiate.

From a human perspective, this may seem an odd arrangement. Even as embryos, we possess many anatomical features of our future adult bodies, albeit often in rudimentary form. Furthermore, only a few temporary structures appear during human development, most notably the transient gill slits that close when we are still early embryos, the placenta that feeds us in the womb, and the baby teeth that erupt soon after birth. Human development is quite direct, involving a fairly steady progression toward adult form.

Not so for most animals. The vast majority begin life as larvae that differ drastically from the corresponding adults. Many familiar animals have a larval form: caterpillars turn into butterflies, and tadpoles into frogs. But it is among the ocean's marine invertebrates that the larval lifestyle is most dramatically displayed. By one estimate, about 170,000 species of marine invertebrates exist worldwide, including not only sea stars but also sea

PETER PARKS, IMAGE QUEST 3D

A spiny lobster larva hitches a ride on a jellyfish. After being at sea for two years, the larva will swim against the current back to coastal waters and undergo metamorphosis.

ART

To see larvae in action, go to www.naturalhistory.com

And Then There Were Two

Cloning in Sea Star Larvae

By Elizabeth J. Balser and William B. Jaeckle

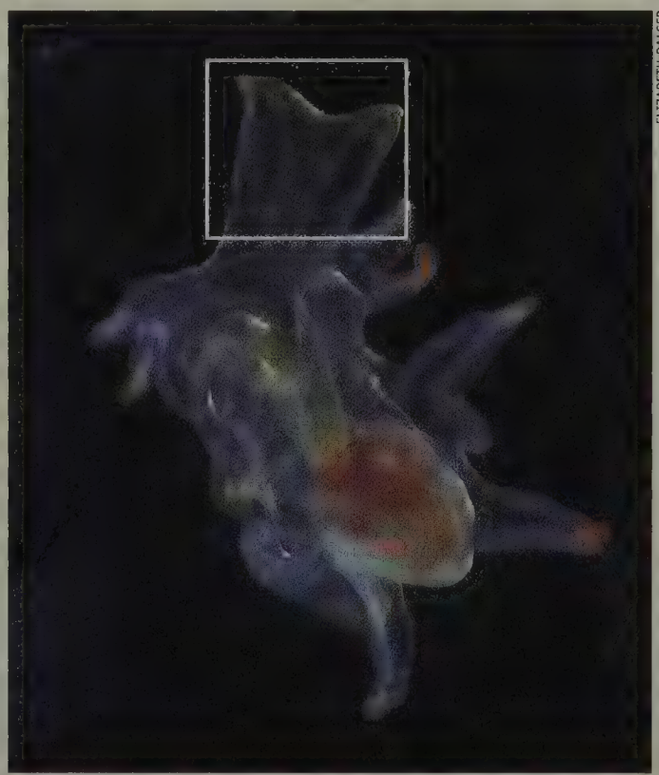
In 1989 scientists reported an astonishing discovery: cloning by sea star larvae. Isidro Bosch, of the State University of New York College at Geneseo, and several colleagues observed larvae with small growths, or buds, in place of one or more of their larval "arms." After separating from the primary, or "parent," larva, these buds developed into fully formed swimming larvae. Long before reaching adult form, let alone sexual maturity, these immature lifeforms were in essence giving birth to other, genetically identical individuals.

In the years since Bosch's discovery, we, too, have found instances of cloning among the larvae of several sea star species as well as among at least three species of brittle stars. Larvae of sea stars collected from the western Atlantic Ocean exhibit three distinct cloning methods. Most commonly, clones develop from the posterior arms of the parent larva (which, unlike the radially symmetrical adult, is bilaterally symmetrical, with a front and a back end). In the second method, all ten larval arms release buds that develop into independent larvae. In the third, the preoral lobe (a region in front of the mouth) separates from the primary larva, which then regenerates its preoral lobe, while the released lobe forms its own larval body.

From the mother sea star's point of view, larval cloning is a reproductive bonus: with no more investment on her part, she winds up with many more offspring. From the larva's perspective, cloning is a way for one "individual" (the primary larva and all the genetically identical larvae it produces) to extend the amount of time it has to find a suitable place (or, in this case, places) to settle and metamorphose into adult form. A longer period of dispersal tends to mean a wider dispersal as well, which may eventually help a species populate new areas. Less benignly, of course, a longer dispersal also increases the period of vulnerability to predators. Presumably, however, in order for larval cloning to have evolved, the benefits must, at least some of the time and under some circumstances, outweigh the costs (for instance, when suitable habitats for the adult are few and far between).

ELIZABETH BALSER

Two clones (white globes) develop from the rear "arms" of a sea star larva.



ELIZABETH BALSER

The preoral lobe (see box) of this larva will soon break free and form a new, independent larva, while the "parent" left behind will regenerate the lost lobe.

Once cloned, a larva develops no differently than an embryo arising from a fertilized egg. This suggests that cloning restarts the developmental process or, alternatively, begins some as-yet-undiscovered parallel developmental pathway. Understanding the patterns of gene expression during cloning could have far-reaching value in studies of the evolution and control of development—particularly since cloning by free-living larvae may turn out to be a characteristic typical of other invertebrate phyla. In the words of the renowned larval ecologist Gunnar Thorson, "Who knows? Nobody has ever looked for it!"

urchins, sea cucumbers, sea slugs, and sea lilies, as well as corals, clams, barnacles, and feather-duster worms. These animals typically spend days, weeks, or even months in larval form, mostly swimming in the top ten to twenty feet of water in the company of myriad other creatures. (One bucketful of seawater might contain the larvae of a dozen or so species of marine invertebrates.) At the end of the larval stage, the animals drop down to the seafloor and metamorphose into adults. There they live, grow, and eventually reproduce, releasing sperm and eggs into the water and beginning the cycle again.

The marine invertebrate larvae are so small that their discovery came only in the late 1700s, with the development of good microscopes. Samples of seawater examined through these new instruments revealed a world teeming with unfamiliar organisms. Early observers believed that these tiny creatures must be the adults of previously unknown species, and they named them according to the animals' often bizarre shapes—such as pilidium (from the Greek word for "hat") or auricularia (from the Latin for "ear").

Barnacle larvae found crawling on adults, for instance, were thought to be parasites—a misconception not corrected until the 1820s, when Irish surgeon and amateur naturalist John Vaughn Thompson observed them metamorphosing into immature barnacles. Zoologists initially responded to his findings with disbelief; for centuries, many people had believed that goose barnacles were the young of real geese (hence the barnacle's common name), and zoologists were understandably wary of this new and seemingly equally fantastic claim.

Two decades after the publication of Thompson's findings, German physiologist Johannes Müller accidentally discovered a second example

PETER PARKS; IMAGE QUEST 3D

Equipped with long spines that it flares open when attacked, an early-stage larva of a marine worm, above, bears little resemblance to the adult it will become. The late-stage scale worm larva, left, is beginning to look like its adult self.

while studying a microscopic creature to which he had earlier given the scientific name *Pluteus paradoxus*, or "strange easel"—an apt name for a creature whose triangular profile and projecting "legs" gave it the general appearance of an artist's easel, albeit a nearly transparent one flecked with bright red spots. Müller was surprised to observe a miniature brittle star (a slender relative of sea stars) growing inside the body of this minute animal. His continuing patient observations revealed that the two creatures were in fact one and the same: the adult develops inside the swimming larva, whose body is cast away when the adult takes up residence on the seabed.

FRED BAVENDAM; MINDEN PICTURES

One by one, nearly all the creatures in the peculiar microscopic bestiary of ocean water were found to be the larval stages of familiar animals. By the beginning of the twentieth century, scientists could confidently assert that a complex life cycle with an extended larval "detour" is in fact the most common method of development in the animal kingdom. This newly discovered complexity raised several questions: Why is the larval stage such a widespread feature of animal life, and if it is advantageous, why don't all animals go through one? And why do larvae look so bizarre?

One key insight into these questions came during the 1920s from Walter Garstang, an English embryologist and amateur poet. Garstang was among the first to argue that larvae are intricately adapted to their planktonic world, a world so differ-

Right: The nudibranch, or sea slug, larva starts out with a shell and four ciliated feeding lobes. (The larva's eyes are visible as two black dots.) Above: At metamorphosis, nudibranchs crawl out of their shells, with many species trading armor for toxicity, which they advertise with bold markings.

Getting to the Point

Self-Defense in Crab Larvae

By Steven Morgan and Skyli McAfee

Of the many predators that crab larvae face, plankton-eating fishes (such as anchovies and silversides) pose the greatest threat. Female crabs living in the marshes, mangroves, and sea grass beds of estuaries and bays—the productive but perilous habitats where such fishes are especially abundant—brood their embryos beneath their bodies until the embryos have developed into larvae and are ready to be released. The release is timed carefully: it occurs under cover of darkness, when fish are least active, and during the strongest ebb tides of the month, when the vulnerable crabs-to-be have the best chance of being swept out to the relatively safer waters of the open continental shelf.

PETER PARKS; IMAGE QUEST 3D

The long spine of this porcelain crab larva may deter predatory fish.

Their conspicuousness already reduced by partial transparency, the larvae of many species further boost their chances of survival by descending into dimly lit waters during the daytime and ascending only at night to feed in the more productive surface waters. If approached by a fish, a crab larva generally does not attempt to avoid or escape attack. Instead it relies on a heavily armored exoskeleton and spines that effectively increase its size many times over. In addition, a pair of antennal spines flare upon attack, transforming the larva into a prickly ball, difficult for small-mouthed planktivorous fishes to swallow. Indeed, young fish sometimes die when larvae catch in their throats.

To avoid such a fate, a fish may attack a larva repeatedly before swallowing it, spitting it out each time in an attempt to break down the spines. After the initial strike, the larva plays dead: its antennal spines collapse, and it sinks quietly away. Remarkably, larvae can survive multiple strikes, regenerating broken spines during the next molt or two.

A similar set of defenses has arisen in other lineages of marine invertebrates. The larvae of polychaetes (segmented marine worms), for example, are also largely transparent and sink to safer depths during the daytime. Attacked, they roll into a ball and, like crab larvae, flare their bristles and play dead.

Some crab larvae complete their development in the estuaries and bays where their mothers released them. To help their young survive, the females in these species invest more energy per offspring than do other crab mothers—producing fewer, but larger, eggs and brooding them for a longer time. The result is larger and very long-spined larvae with a relatively short development time of about two weeks. Conversely, short brood times, small eggs, small body size, and short spines are common in species whose larvae migrate offshore and back during development.

When the time comes to metamorphose into adult form, the larvae (or more precisely, postlarvae) of coastal crabs must return to shore, regardless of how far they may have drifted. Riding a flood tide at night on this last journey, enough of them make it past the predatory fish to start the cycle anew.

ent from the seafloor habitat of adults that few features of anatomy could serve a useful purpose in both locations. Take, for example, cone snails (or cone shells, as they are known to collectors): the adults crawl about the seabed, while the larvae are swept along by currents near the ocean's surface; the adults are active predators, armed with potent neurotoxins, while the larvae are herbivores that capture single-celled algae with the aid of microscopic cilia; and the adults are preyed upon by octopuses, while small jellyfishes and a great variety of other tiny predators feed on the larvae. The contrasts are enormous.

Pointing to transient larval organs that form no part of the adult, Garstang argued that the rigors of life among the plankton drove the evolution of numerous and seemingly bizarre adaptations in the early part of the life cycle: the highly convoluted tracts of cilia on the larvae of clams and acorn worms, used for swimming and feeding; the long spines on some annelid worm larvae that flare in response to the slightest touch; and the specialized,

The Long and the Short of It

"Arm" Development in Sea Urchin Larvae

By Larry R. McEdward

Like sea star larvae, most sea urchin larvae have little "arms" lined with rows of cilia that gather nutritious particles suspended in the water. Remarkably, when food is scarce, a sea urchin larva's arms grow longer, thus providing more cilia with which the animal can capture food.

If long arms are beneficial, why would larvae ever have short ones? One possible advantage is that when food is abundant, nutritional intake is limited only by how much a larva can digest—arm length is irrelevant. In fact, smaller arms may allow a larva to devote more energy and materials to increasing the size or activity of its gut. Another advantage is that short-armed larvae start developing into juvenile sea urchins sooner than do long-armed individuals. These larvae will also metamorphose into adults sooner than their long-armed brethren and thus are vulnerable to planktonic predators for a shorter period of time.

PETER PARKS; IMAGE QUEST 3D

Many sea urchin larvae can modify their "arms" in response to food supply.

My graduate students and I are currently investigating several aspects of larval plasticity in sea urchins. (Plasticity is the ability to produce different body forms under different environmental conditions.) Though we have not yet isolated the specific cues that trigger modifications in structure, function, or development, we have learned that different species respond to different cues, with some larvae able to detect cues and alter arm length even before they have begun to feed. We also want to learn how this plasticity is related to other larval attributes. For example, not all species pack their eggs with the same amount of nutritional material. Larvae that develop from protein- and lipid-rich eggs have a greater capacity to modify their early development and to exhibit plasticity, even though larvae from poorly provisioned eggs are more dependent on food from the plankton and would thus, we might think, benefit more from an ability to modify their bodies in response to environmental conditions. One long-term hope of our team is that understanding the mechanisms by which short and long arms are generated in different species will help us determine if larval plasticity arose once, early in the evolutionary history of sea urchins, or numerous times.

suckerlike organs used by the larvae of sea squirts and sea stars to adhere to rocks or shells during metamorphosis.

Although Garstang's observations and conclusions may now seem almost obvious, they went against the then-prevailing view. Just half a century earlier, the German comparative anatomist Ernst Haeckel had forcefully argued that embryonic development retraces the course of evolutionary history. Haeckel, who interpreted larvae as vestiges of ancestral adults, remained influential well into the twentieth century. In arguing that its anatomy specifically adapts a larva for planktonic life, Garstang challenged Haeckel's paradigm and, indeed, played an important role in its eventual demise as a general principle. (Garstang's poetry remains popular among biologists today, in large part because it venomously satirizes Haeckel and other intellectual opponents.)

But why would young need a body plan and habitat different from those of adults? In Garstang's view, the answer was dispersal. Local habitats—whether a suitable rock, a chunk of coral reef, or a bit of sandy sea bottom—inevitably suffer periodic disruptions from silt deposition, unusually violent storms, disease outbreaks, and the like. Setting great numbers of offspring adrift in the ocean increases the chance that at least some will survive and be delivered to suitable locations, a strategy that contemporary ecologists call bet hedging.

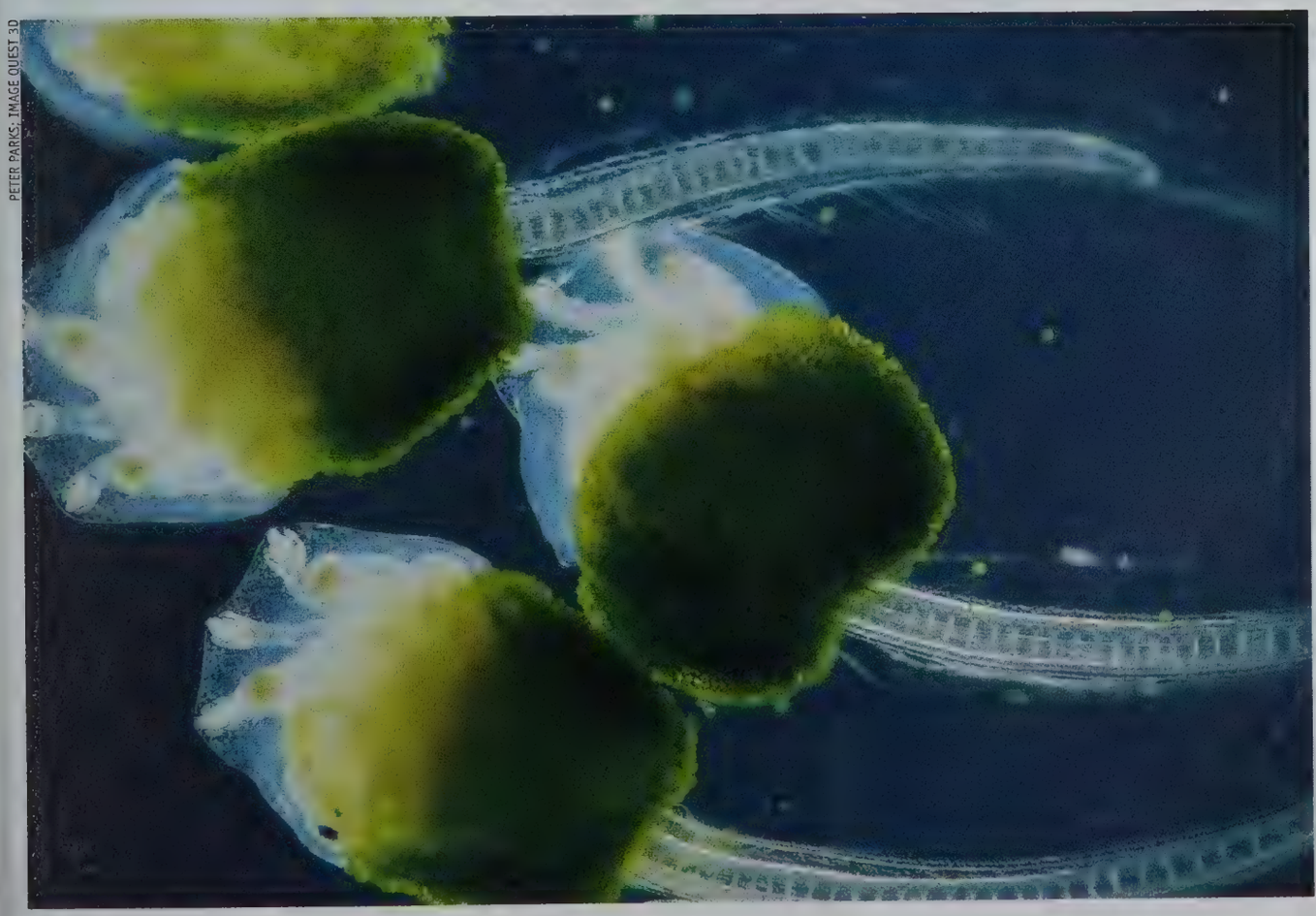
Larvae's ability to drift long distances also provides a mechanism for genetic mixing. Many adult

marine invertebrates have only a limited ability to move, and some, such as corals and barnacles, do not move at all. Inbreeding is a real danger for creatures that are (quite literally, in some cases) stuck in one place. Widespread dispersal helps ensure that when larvae do settle down, their neighbors—and potential mates—will be unrelated.

Although dispersal provides tangible benefits, the cost is high. Among the plankton are numerous diminutive but voracious carnivores, including small jellyfishes and comb jellies, saber-toothed creatures called arrowworms or chaetognaths, and a host of crustaceans and small fishes. Larvae that are not eaten are still prey to the ocean currents, which can sweep them away from suitable habitats. And when "suitable habitat" means a coral reef in the Pacific Ocean—separated from the next reef by perhaps a thousand miles of open ocean—almost any current is likelier to move a larva away from safety than toward it.

Yet the broad geographical distribution of many species of marine invertebrates across the South Pacific is proof that larvae do sometimes successfully drift from reef to reef, crossing over abyssal depths that adults could never negotiate. Just how far from its birthplace a larva may drift became clear in the 1970s, when oceanographers, using fine-mesh nets similar to those invented by Thompson a century and a half earlier, began a systematic sampling of plankton in the middle of oceans. These plankton hauls often included the larvae of clams, sea stars, and other invertebrates whose adults live only in the relatively shallow water of continental shelves. We now know that the Gulf Stream sweeps countless larvae out of the Caribbean Sea and into the North Atlantic, where most perish and perhaps a tiny fraction survive long enough to ride the entire gyre to Europe and back across to the Caribbean.

PETER PARKS: IMAGE QUEST 3D



PETER PARKS: IMAGE QUEST 3D

Left: Sea squirts have a short larval life, swimming with the aid of a tadpolelike tail for just a few minutes before settling on the seafloor, to which they attach themselves with little "suckers" (visible at the front end). There they will transform into filter-feeding adults, above.

ELIZABETH BALSER

As a sea star larva prepares to settle on the seafloor, it grows an attachment organ with sticky "arms" and a central adhesive disk (see bracket). The adult-to-be (yellowish sac) forms from the lower part of the larval body. Eventually the rest of the larval body, except for the stomach (orange), is absorbed into the developing juvenile.

All these hazards take a heavy toll. Estimates of larval death rates range from 10 to 20 percent per day. Even at the lower rate, barely one-fifth of a brood will survive two weeks among the plankton, and only a few percent will last a month. (Most larvae must feed for weeks or months before they grow large enough to undergo metamorphosis.) Such heavy mortality suggests that natural selection will favor the evolution of well-defended larvae that eat efficiently, grow quickly, drop out of the plankton community in short order, and soon undergo metamorphosis—just as Garstang and others suggested nearly a hundred years ago. The idea has only recently been tested in detail, however.

Using time-lapse microscopy, Michael Hart, an evolutionary biologist at Dalhousie University, has observed echinoderm larvae capturing food particles and then quantified their feeding rates. Comparing the rates of sea urchin and sea star larvae, he found that those of sea urchins were higher and that these larvae reached metamorphosis sooner. Anatomically the two kinds of larvae are quite similar, and both use the cilia along the sides of their bodies to sweep algae toward their mouths, but the sea urchin larvae also develop long projections lined with hundreds of cilia, which help the larvae pull in even more food. Specializations for feeding abound among immature marine invertebrates. The cilia on the larvae of acorn worms capture algae; strings of mucus serve as "fishing" lines for some sponge larvae; and the larvae of lobsters and shrimp use powerful claws to grab unwary prey.

Well-fed or not, larvae face the problem of predation. The larvae of many groups defend themselves with spines and spikes, which can be impressive. Some shrimp larvae sport sharp spines extending more than five times their body length. Other defensive strategies include toxicity (some sea squirt larvae) and concealment (larval snails that hide in their shells). And nearly all marine invertebrate larvae enjoy the advantage of transparency.

To study how larvae defend themselves from predators, Steve Rumrill and Tim Pennington, then graduate students at the University of Alberta, set up aquariums with different combinations of predators (adult jellyfish and juvenile fish, for example) and prey (sea urchin embryos and larvae in various stages). They found that the embryos and younger larvae were especially vulnerable because they had not yet developed their feeding projections, inside of which are spiny spicules capable of deterring some predators, such as jellyfish. But nothing stopped the fish, whose mouths opened wide enough to swallow even late-stage urchin larvae whole.

Even if a larva manages to get enough to eat and to escape being eaten, it confronts the challenge of finding an appropriate place to settle and undergo metamorphosis. Those fortunate enough to drift near the right habitat at the right time must still select exactly the right site. Settling near a hungry snail could be disastrous for a peanut worm, and landing too far from kelp would doom a sea urchin to starvation. As the time for metamorphosis approaches, most larvae become acutely sensitive to chemical cues that signal the presence of food, conspecific adults, and potential hazards. The importance of finding a good place to land is underscored by the fact that the decision, once made, is often final: many larvae bear specialized structures that glue them to their chosen spot.

Metamorphosis itself must coincide with settlement on the seafloor, an environment so different from the surface that no larva would long survive unchanged—just as no adult could handle life in a planktonic world. Metamorphosis can be dramatic and literally gut-wrenching. Almost immediately

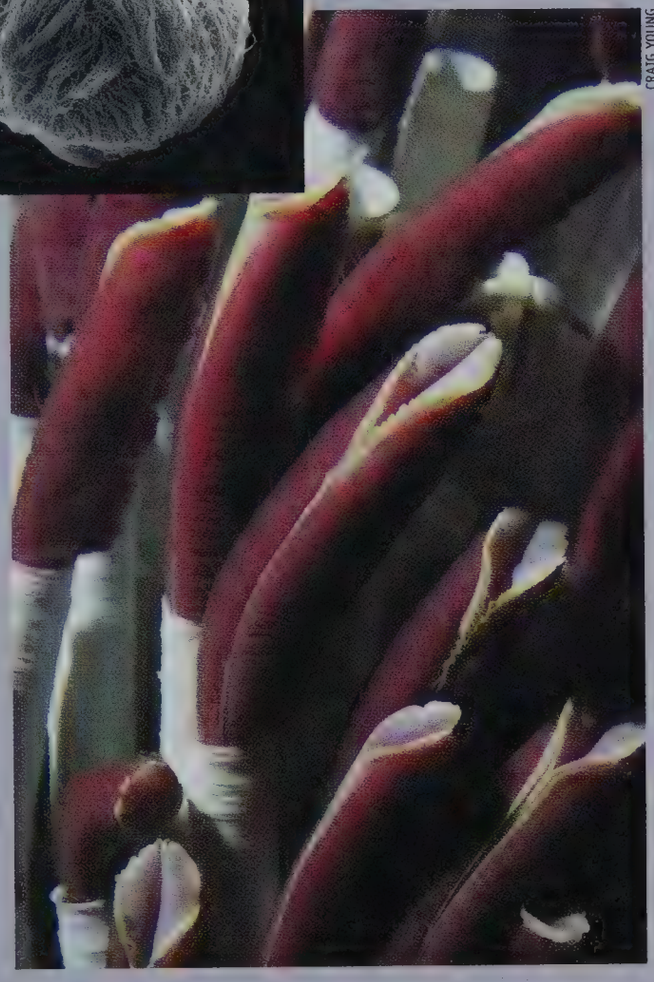
Out of the Frying Pan, Into the Freezer

Larvae at Deep-Sea Vents

By Craig M. Young

A quarter century ago, when scientists discovered lush colonies of organisms surrounding hot-water vents, such as black smokers, on the ocean floor, they began wondering how these animals maintained their populations. The giant tubeworms, specialized clams and mussels, and wide assortment of tiny snails, crabs, shrimps, and other worms that live around the vents are nourished by bacteria, which in turn obtain their energy from hydrogen sulfide in the hot water emanating from deep within the earth's crust. Completely dependent on vent water, these species cannot survive even a short distance away. Because the hot-water plumbing of the seafloor is controlled by unpredictable volcanic activity in the earth's interior, a vent may remain open and active for only limited periods—years or sometimes decades. Moreover, areas of active venting may lie hundreds of miles apart. Researchers suspected that many, if not most, of the vent animals must produce larvae capable of dispersing through cold ocean water to new sites.

CRAIG YOUNG


CRAIG YOUNG

Above: Adult giant tube worms at hydrothermal vents in the Pacific Ocean. Inset: An electron micrograph of the larva of a related species from cold methane seeps in the Gulf of Mexico.

Searching for larvae, researchers from the Woods Hole Oceanographic Institution towed plankton nets near vents on the East Pacific Rise. They captured relatively few—except in the buoyant plumes that rose directly above hot smokers. Here the larvae of various snails and polychaete worms were abundant, suggesting that some larvae may begin their voyage from one vent field to another by drifting in the slightly warmer waters near vents. On the other side of the world, larvae of the abundant shrimp found around vents on the Mid-Atlantic Ridge have been captured more than half a mile above the bottom and more than 900 miles from the nearest vent, suggesting that free-swimming larvae do indeed travel long distances.

Because vent animals live at such great depths and under tremendous pressure, the details of their development and ecology have been difficult to determine. Only recently, after years of work, have we reared tubeworm larvae in our laboratory. The first ones we succeeded in raising came not from vents but from shallower, 2,000-foot-deep communities at cold methane seeps on the Louisiana continental slope. Now, with colleagues from the University of Southern California, we have also cultured the larvae of giant tubeworms from deep Pacific vents, and they are gradually yielding the details of their dispersal mechanism.

Tubeworm eggs and embryos are richly endowed with all the lipids and protein needed for embryonic development and larval dispersal. And because lipids are less dense than seawater, they also aid dispersal by causing the larvae to rise toward the surface. After drifting for several weeks, the embryos develop into ciliated larvae and swim actively for about two weeks before locating a suitable habitat and transforming themselves into small worms. We don't yet know what precipitates the larval migrations of giant tubeworms or other vent animals back to the ocean floor, nor do we know how they locate suitable habitats. We suspect that they cue in on certain attributes unique to vents: the presence of sulfide, hot water, or perhaps other vent organisms.

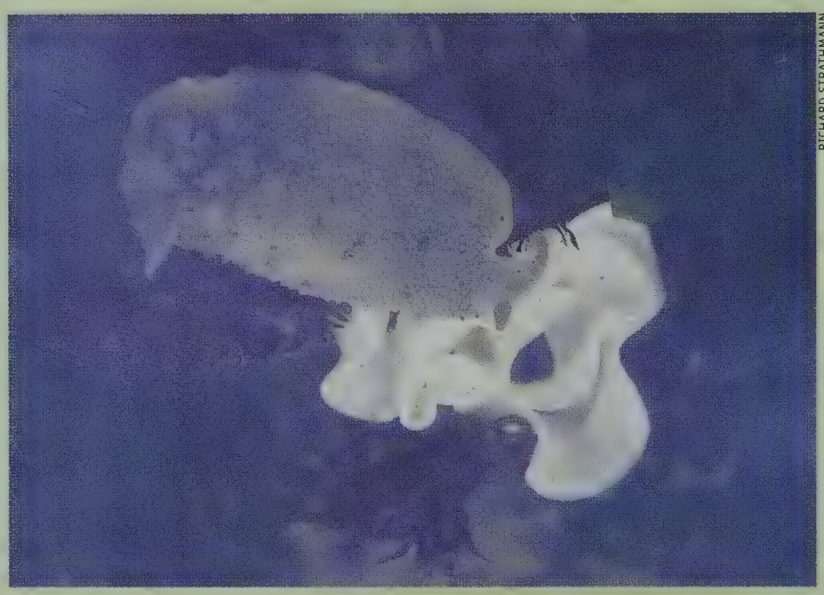
A Method for the Masses

Oxygen Delivery for Stay-at-Home Embryos

By Richard Strathmann

Most marine invertebrates set their young adrift. Some, however, produce masses of embryos that remain at the bottom of the sea, where they may be protected by tough capsules, by layers of gel, or by the body of a parent. Though these embryos are safe from the many planktonic predators, life in an embryo mass is not without its challenges.

Perhaps the most vital challenge is getting enough oxygen. Not very soluble in water, oxygen diffuses in it at about 1/10,000 the rate oxygen diffuses in air. For free-swimming larvae, this presents no problem. But for embryos packed together in a mass—with no circulatory system and no way to force oxygen-bearing water rapidly through the tiny spaces between small eggs—the problem can be severe.



RICHARD STRATHMANN

A nudibranch laying its gelatinous, ribbonlike egg mass

One solution is to keep the mass small and thus the need for oxygen relatively low. Accordingly, species in which mothers brood their embryos on or in their bodies tend to be the smaller species of sea stars, sea cucumbers, clams, and feather-duster worms. Larger species of marine invertebrates that brood their young have evolved special ventilation mechanisms. A large crab or lobster may incubate more than 100,000 embryos, but each one is held loosely on a separate strand. Oxygenated water is forced through the mass of embryos by the mother's movements; to increase circulation around her brood, a mother crab waves her abdomen up and down.

Other species, including many snails, secrete strong, flexible, thin-walled capsules around their eggs and attach each capsule to a rock or to seaweed in moving water. Some snails, sea slugs, and worms embed embryos in gel, often in the form of thin strings or beautiful coiled ribbons that undulate gracefully in the current. Even within a thin ribbon, however, embryos will die if packed too tightly. The thicker the mass, the more of it must be devoted to gel, thus lowering the demand for oxygen within a given volume.

Sometimes these embryo masses are thick and globose and are anchored in the sand by a buried strand of gel. Masses of this type range from a quarter inch to several inches in diameter and have a high proportion of gel. Embryos in the center of the mass receive less oxygen than those at the periphery and, as a result, develop more slowly. In some masses, the central embryos die; in others, as the peripheral embryos hatch and leave, those in the center start receiving more oxygen and are able to complete their development.

Some of these protective measures have their costs, of course. The capsule walls of cone snails and the gel around nudibranch eggs constitute between one-quarter and one-half of the organic material in the mass. If the mother produced only eggs, and not the additional protective coats or spacing gel, she could produce up to twice as many. What makes the trade-off worthwhile is the increased survival of her young.

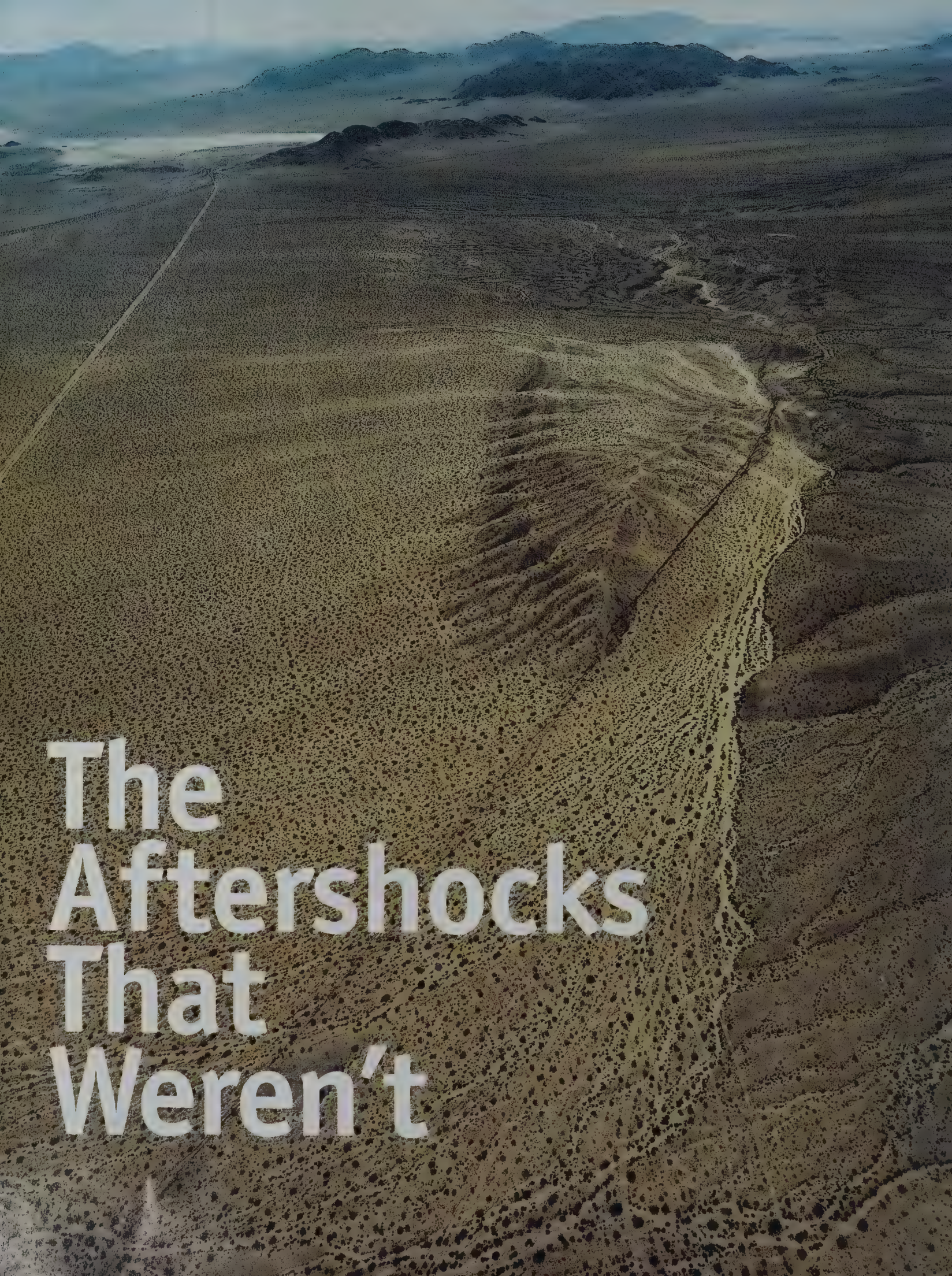
after attaching to a rock or a blade of kelp, for instance, the larva of a bryozoan begins a violent rearrangement of its internal organs and external appearance. Pockets of sticky cells evert, securing the animal in place; other cells evert to form the outside of the adult; still others secrete a tough shell; and muscles quickly fold the former larval body wall inside the newly forming adult, where it is resorbed. In many ribbon worms and echinoderms, metamorphosis is remarkably rapid, with the major changes from larval to adult body form taking less than half an hour.

And then there are larvae that have no need to feed at all—including those of some clams, snails, sea stars, and annelid worms. Nonfeeding larvae are generally much simpler anatomically than the feeding larvae of related species, having jettisoned useless feeding structures and significantly accelerated the events leading to metamorphosis. In these species, eggs are provisioned with enough protein and fat to fuel development all the way through metamorphosis. This shift to dependence on maternally provided food reserves has evolved within most groups of animals and at many junctures in the history of life. In the most extreme cases, a distinct larval stage is lost altogether, and embryos develop directly into miniature versions of adults. This evolutionary shift, too, has occurred many times—groups as diverse as squids, roundworms, and most vertebrates develop without the benefit of larvae.

Why don't all species adopt this trick of minimizing or even bypassing the larval stage? Because neither having nor lacking a larva is inherently superior. Each has costs and benefits, and the balance shifts among groups of animals and across the myriad habitats of the marine realm. Species with feeding larvae, for example, produce small eggs and consequently can afford to have much larger broods, whereas species with nonfeeding larvae or direct development tend to produce larger eggs or to have placentas and therefore much smaller brood sizes. Predators may also affect the duration of larval development: species heavily preyed on as small juveniles may be better off prolonging their time among the plankton, but others may do better to settle on the seafloor as quickly as possible and thus avoid planktonic predators. Understanding the particular ecological contexts that favor the evolutionary retention, reduction, or loss of larvae represents one of the outstanding challenges facing biologists today. For now, however, we can say that although larvae don't offer the only road to adulthood, for most animals they provide a good way to get there. □

FRED BAVENDAM; MINDEN PICTURES

Some marine invertebrates—like these young octopuses peering out of their egg cases—skip the free-living larval stage and develop directly from embryo to adult.


The
Aftershocks
That
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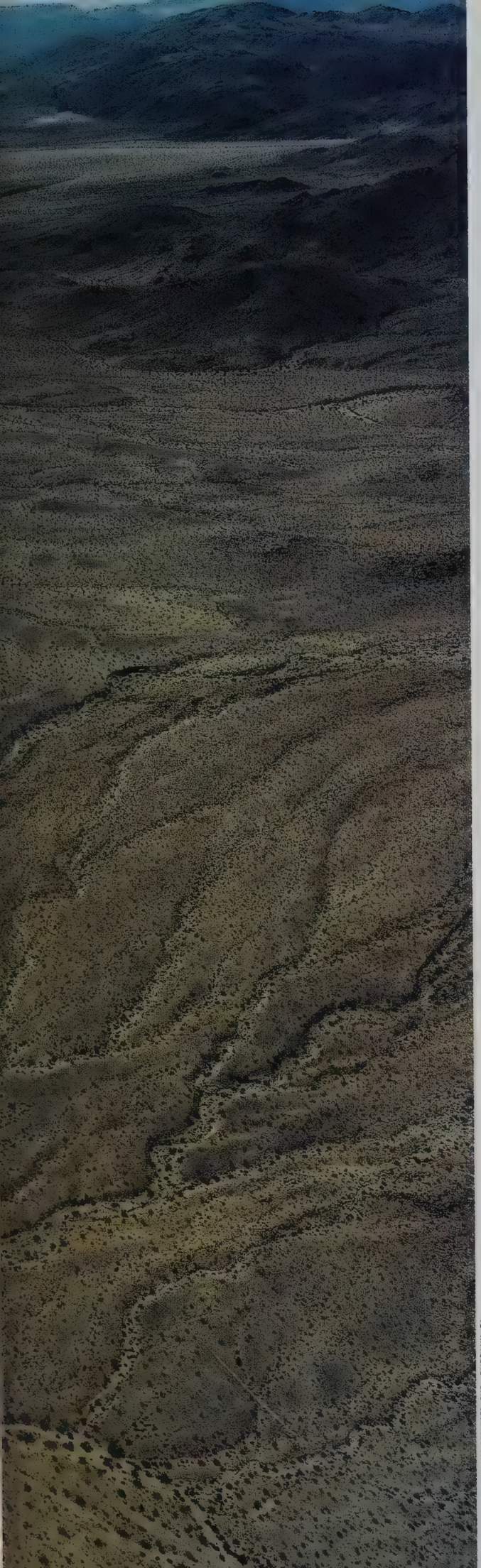

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An aerial view looking southeast across the Mojave Desert shows a rupture (running from the lower left toward the upper right of the photo) created by the 1992 Landers, California, earthquake.

By Susan Elizabeth Hough

Before dawn on June 28, 1992, residents of southern California were jolted from their sleep by a magnitude 7.3 earthquake. The temblor started beneath the tiny Mojave desert town of Landers, but its effects were felt in Los Angeles, ninety miles to the west, as well as in northern California, southern Nevada, and at the Mexican border.

Earthquakes are not unusual for California, of course. The state is riddled with both large and small faults at the boundary between two tectonic plates: the North American Plate and the Pacific Plate. These two enormous pieces of the earth's crust are constantly sliding past and grinding against each other, creating an active and complicated boundary zone. Sections of faults often rupture here, earning California its reputation as earthquake country. So the powerful Landers temblor was not unusual in itself. Its far-reaching aftereffects, however, revealed some surprises.

Nearly half a century ago, seismologist Charles Richter, of Richter scale fame, observed that "an earthquake of consequence is never an isolated event." He was referring to the aftershocks that invariably follow a large temblor, or main shock. As earthquakes go, aftershocks are remarkably well behaved. In time, space, and magnitude, they follow predictable patterns that have been recognized by seismologists for decades. As a general rule, they are small, more frequent in the immediate aftermath of a main shock, and usually clustered no farther from the site of the main shock than the length of the rupture it created.

New evidence from California—and old reports from the Midwest—indicate that some earthquakes can trigger others hundreds of miles away.

The Landers temblor, however, permanently changed the established view of earthquake sequences. In the minutes and days that followed the quake, a substantial number of smaller seismic events occurred well beyond its aftershock zone—as far away as the Lassen Peak area and at the Geysers, about sixty miles north of San Francisco. The largest of these distant events, with a magnitude of 5.4, struck in western Nevada twenty-two hours after the Landers event. Quickly dubbed remotely triggered earthquakes, these outlying seismic events seemed to be different beasts from anything seismologists had previously encountered.

Because the Landers quake was one of the first magnitude 7.0 events to be recorded by state-of-the-art seismic stations throughout California, it yielded the first solid evidence of distant earthquake triggering. The authors of one research paper commented that "no previous experience would have led us to anticipate the observations of remotely triggered [earthquakes]." Earth scientists began to realize that large quakes could perturb the crust in complex ways that earlier theories could not explain.

The powerful Landers earthquake of 1992 triggered hundreds of distant events, many clustered in four areas in California and Nevada, and all far beyond the aftershock zone.

Almost immediately after Landers, researchers began to focus on these puzzling quakes. Not only were they located too far from the main shock to be classified as aftershocks, they also couldn't even be associated with the same physical mechanisms. As the Landers earthquake helped seismologists understand, conventional aftershocks appear to result primarily from local, mechanical factors—changes in stress caused by large-scale movement of a crustal block. But as seismologist Joan Gomberg and others have shown, the outlying earthquakes of 1992 were apparently set off solely by waves, or shaking, emanating from the Landers main shock. Such waves, it seems, were capable of engendering—that is, triggering—new quakes as far as 700 miles away.

Using data not only from Landers but also from Greece and Mexico, seismologists attempted to characterize the geology of vulnerable areas and to define a threshold level of shaking needed to trigger remote events. The first models implicated something curious: bubbles. Most of the triggered quakes identified in the immediate aftermath of Landers had taken place in regions with active volcanoes or geothermal features such as geysers. A couple of models showed that disruption of the bubbles within fluid reservoirs can indeed raise stress on faults, which, the researchers argued, could then set off earthquakes. According to this scenario, triggered earthquakes were rather exotic events occurring only in highly unusual geological zones.

The first computer studies of triggered quakes implicated the disruption of gas bubbles in subterranean reservoirs of fluid.

Last year, however, I took a new look at evidence from an unlikely time and place, and my investigation has revealed that the triggered earthquakes of 1992 were not as unprecedented—or as exotic—as they first seemed. Nearly two centuries ago, settlers along the Ohio River valley wrote reports that (had they been fully appreciated) might have helped scientists interpret what happened after the Landers earthquake. In the wee hours of the morning on December 16, 1811, the usually stable U.S. midcontinent was rocked by an earthquake so large that it caused damage as far away as coastal South Carolina. Now estimated to have had a magnitude upwards of 7.3, the temblor was the first event in an extraordinary sequence. Centered at the southeast corner of Missouri—the Bootheel region, adjoining the Tennessee-Kentucky border—the sequence was named New Madrid, after a town close to the event. The area experienced two more quakes after December 1811: events of comparable

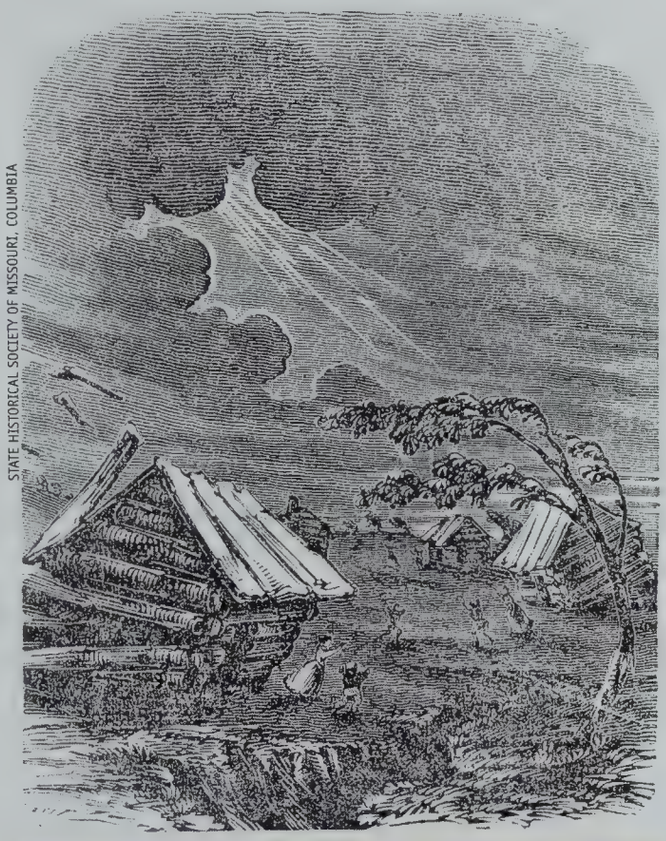
magnitude jolted the region on the mornings of January 23, 1812, and again on February 7, 1812. Historical accounts peg the final quake as the largest of the three; some refer to it as the "hard shock." Immediately following it, a section of the Mississippi River in the vicinity of New Madrid reversed course for several hours.

Starting in the 1970s and early 1980s, seismologists Otto Nuttli, Ronald Street, and Arch Johnston compiled and interpreted the available accounts of the New Madrid sequence, including reports of half a dozen "large aftershocks" on the Atlantic coast. Settlers left descriptions of thousands of perceptible aftershocks, most not large enough to rattle anything more than people's nerves, but some so strong they cracked chimneys and split stone houses.

Recently my own attention was drawn to historical accounts of the effects of the New Madrid sequence. I was especially struck by passages concerning three particularly large "aftershocks": one that occurred four days after the January 23 event and two others on the night of the February 7 "hard shock." These supposed aftershocks were apparently centered near the Ohio-Kentucky border; no accounts exist from within 200 miles of New Madrid. To a seismologist reviewing the evidence, this absence of reports in the region of the main shocks is contrary to expectation. Moreover, descriptions of the shaking in Ohio and Kentucky differ significantly from accounts of the New Madrid main shocks. Daniel Drake of Cincinnati stated that one of these "aftershocks" caused "a very sensible degree of trembling, but no oscillation." Jared Brooks of Louisville wrote that another was "violent in the first degree" but "of too short duration to do much injury." These accounts were exciting to read. Brooks and Drake—an engineer and a physician, respectively—seemed to be describing "jerky" motions of higher frequency than those generated in the region by the distant New Madrid main shocks. Such high-frequency energy is usually damped out as the waves move through the crust and away from the main shock.

I then used a computer mapmaking program to plot the reported distribution of effects from the three major "aftershocks." The results were striking: they revealed a bull's-eye pattern centered in northern Kentucky. I could only conclude that what Brooks and Drake and others had described were remotely triggered earthquakes—the same type of event that took earth scientists by surprise 180 years later.

The New Madrid observations suggest that the "bubbles theory" of the early models may have been a red herring. Yes, the remotely triggered earthquakes documented in recent years occurred disproportionately in regions of active volcanic or geothermal processes—regions where fluid reservoirs are in fact found at the depths at which earth-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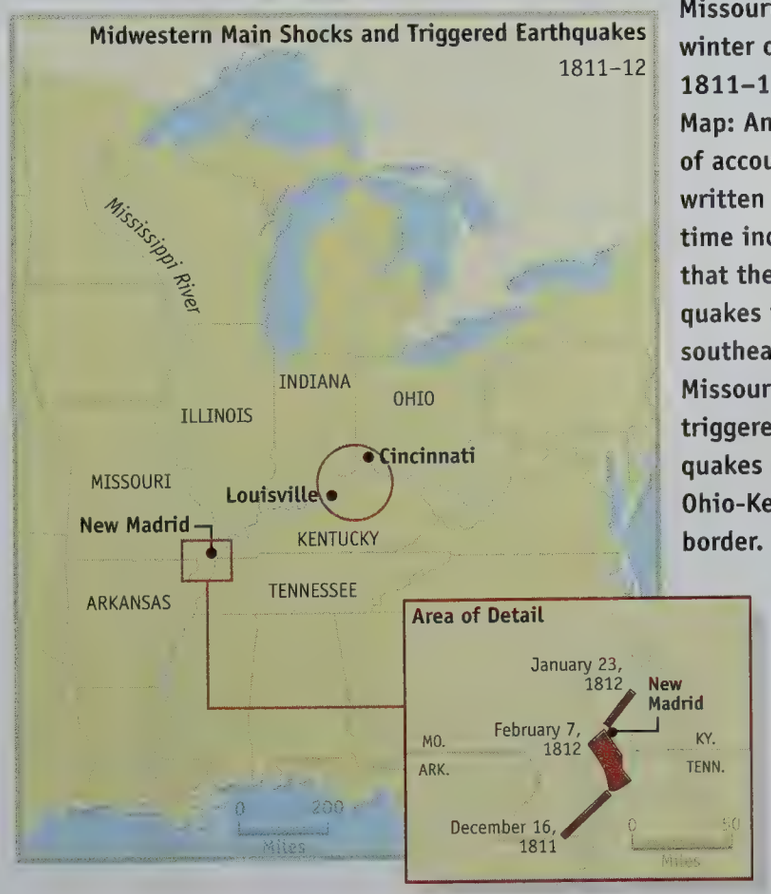

A contemporary woodcut, left, pictures earthquake devastation in New Madrid, Missouri, in the winter of 1811–12. Map: An analysis of accounts written at the time indicates that the three quakes in southeastern Missouri triggered other quakes near the Ohio-Kentucky border.

quakes occur (typically three to twelve miles below the surface). But northern Kentucky has no active volcanic or geothermal features, nor are earthquakes common there.

Some of the most recent observations of remotely triggered quakes also suggest that bubbles and crustal fluids do not play a direct role in the triggering process. The October 16, 1999, magnitude 7.1 quake at Hector Mine, California, triggered events well outside its aftershock zone—in particular, a pronounced sequence near the Salton Sea, a large, low-lying saline lake just north of the California-Mexico border. Because the Salton Sea events occurred within a few miles of a modern seismometer, scientists had excellent data to analyze. And because the area is volcanically and geothermally active, the Salton Sea events also provided seismologists with an ideal opportunity to look for evidence of an exotic, fluid-controlled source in the event recordings. The results of my own recent analyses of the Salton Sea events suggest that, notwithstanding their association with unusual geophysical features, such remotely triggered quakes are nothing more than garden-variety temblors occuring on somewhat weak faults. In active volcanic and geothermal regions, myriad fragile faults may behave somewhat like a delicately balanced pile of pickup sticks—even a small disturbance can disrupt the system. Heat and crustal fluids may therefore facilitate triggering, but only indirectly, by creating an environment in which faults are weak.

MARK ZALESKI; SAN BERNADINO SUN

A ruptured piece of highway in the desert near Landers, California, after the 1992 quake

But if recent triggered earthquakes have generally happened where faults fail easily, what does one make of the New Madrid results? In parts of the crust that are relatively inactive, faults may be numerous, but they are expected to be strong. Recent studies suggest, however, that at any given time in such regions, a relatively large number of faults are probably close to failure. Thus a fairly small disturbance might trigger remote earthquakes in quiet parts of the crust, not because faults are especially weak there, but because where a great many faults exist, some are likely to be only a nudge away from failure.

Newly recognized phenomena, triggered earthquakes can provide important information about fault failure.

What, then, can triggered earthquakes tell us about earthquake processes in general? Scientists do not yet have a complete answer to this question. However, the observations from 1812 to 1999 all seem to carry the same message: that triggered earthquakes are ordinary earthquakes but that they stand to provide us with important new information about fault failure.

One possibility is that earthquakes—all earthquakes—represent nothing more than cracks in the earth that grow very, very slowly in response to the forces applied on them, until the cracking process accelerates into a runaway failure. Such a phenomenon would be analogous to cracking in rocks, a process that can be studied in detail in laboratory experiments. The final kick that initiates the runaway process might be infinitesimally small—perhaps nothing more than the final grain of sand landing atop the increasingly unstable sandpile. Or, as in the case of triggered events, it might be an abrupt kick, delivered by the shaking from a distant earthquake.

The idea of earthquakes as the culmination of runaway crack growth is not new. What is new is that we can now quantify the type of shaking that does, and does not, produce additional earthquakes at distant points. Preliminary results suggest that only quakes close to or above magnitude 7.0 will produce remotely triggered events. Seismologists are able to make rocks crack in the laboratory,

but we have a very limited ability to test the conditions under which actual faults in the crust rupture. We now know that, at least once in a while, the ground beneath our feet performs its own experiments, giving us important new information about how earthquake ruptures occur. And some of these experiments have been available to us all along. The old data just had to wait for new eyes—eyes aided by years of accumulated scientific understanding.

Shortly after the New Madrid quakes, geologist and congressman Samuel L. Mitchill set out to compile and interpret local accounts of those events. His narrative, published in 1815, is among the most valuable sources of information available to modern seismologists for the 1811–12 sequence. After lamenting his failure to formulate a satisfactory theory to explain what had happened, Mitchill notes, "I console myself, however, that the history which I have written will give valuable information to the curious on these subjects, and assist some more happy inquirer into nature, to deduce a full and adequate theory of earthquakes." One hundred and seventy-seven years later, the Landers quake helped put earth scientists in a position to fulfill his hopes. □

California is earthquake country. The San Andreas Fault is easily visible at the surface of the Carrizo Plain.

Mushi

By Erik L. Laurent

Every summer and fall, Japanese children spend hours catching and playing with insects.

From *Companion Animals and Us: Exploring the Relationships Between People and Pets,* edited by A. L. Podberscek, E. S. Paul, and J. A. Serpell.
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Each summer and fall, many Japanese children (mostly boys) spend hours catching and playing with insects, or *mushi*. Live *mushi* are also sold in Japanese department stores and post offices, along with implements for catching and breeding them. Caged "autumn-singing" insects (primarily crickets and grasshoppers) have for centuries been welcome seasonal gifts in the countryside. Although in recent years the tradition of giving children rhinoceros beetles and stag beetles as gifts has lost ground to purchasing tiny electronic creature toys, children still flock to Japan's insectariums, or arthropod zoos. And as homework over summer vacation, many rural schools still assign their eight- to ten-year-old students the task of preparing a collection of live insects.

The first written reference to the selling of autumn-singing insects dates to 1685 in Kyoto. At that time, vendors carried their crickets in big square baskets suspended from poles worn across the shoulders, and they also sold small cages. Many children used to catch their own *mushi,* but insects began to be commercially bred as their popularity increased. Owned by fishermen or peasants, the first pushcarts that sold *mushi* appeared in about 1820. Beginning in the Meiji period (1868–1912), *mushiya,* or shops that sold singing insects, fireflies, and jewel beetles as well as cages and trapping devices, began to spring up. Lafcadio Hearn, the renowned writer on Japan, gives a price list for the twelve most popular species in a chapter on insect musicians in his 1898 book *Exotics and Retrospective*. During the 1930s *mushi* sales began to decline, and by the end of World War II the *mushiya* had almost completely disappeared.

Opposite: A child stalks a dragonfly in a field. Below: A katydid *(Gampsoclesis buergeri),* one of the singing insects favored by young Japanese collectors.

SHINJI KUSANO; NATURE PRODUCTION

The tradition did not die, however. In the 1960s department stores experienced a boom in rhinoceros beetle sales, fueled by the enthusiasm of young boys. Since then, rhinoceros and stag beetles have become the best-selling *mushi*. Several million are now bred and sold during the warmer months.

I recently interviewed a rhinoceros beetle breeder, Akahane-San, who lives in the town of Takatô on the island of Honshū. Akahane had been raising mushrooms but in 1985 switched to breeding beetles. Even though initially only one store in the nearby city of Ina sold his *mushi,* his business prospered and he has expanded the operation. Now his *mushi* are sold in the local post office and several department stores and are also bought by visitors to his farm.

"It's not a very hard job, quite suitable for old people," says Akahane, who keeps thousands of rhinoceros beetles in a fenced breeding enclosure on his farm. He carefully monitors soil conditions but basically leaves the beetles alone. At the end of August they lay their eggs, and the following summer the adults molt. To correct genetic problems that arise from inbreeding, Akahane introduces "new blood" every two or three years by adding wild-caught beetles to the breeding population. He now raises 4,000 rhinoceros beetles each year for the market.

Two major traits that seem to account for the popularity of these creatures are their inoffensive character and their spectacular appearance. Indeed, the black and horny rhinoceros beetle is one of the largest members of the order Coleoptera. Today in the Japanese countryside one sometimes still sees children pulling small carts full of rhinoceros beetles—a pastime that goes back hundreds of years. Little boys will induce the rhinoceros beetles to fight each other for a small piece of watermelon or will make them pull weights.

Each species of *mushi* is associated with a season of the year, and some even with a particular time of day. Traditional *mushi* games, likewise, are seasonal. In the spring children catch butterflies, and in the summer they play with aquatic whirligig beetles,

MITSUHIKO IMAMORI; NATURE PRODUCTION

The bell cricket *(Homoeogryllus japonicus)*, right, is prized for its musical chirping. Below: An insect imprisoned in a cage made of a hollowed-out *kabocha*, or pumpkin.

true water beetles, and snails. Summer is also the time to catch fireflies and cicadas and to adopt rhinoceros and stag beetles as pets. Catching dragonflies, collecting *tsuchibachi* wasps' larvae, playing with ant lions and *batta* locusts, and learning to make *mushi* cages from straw are all traditional summer activities. In autumn children listen to singing insects, observe and play with red dragonflies, collect *inago* locusts, stage spider fights, watch mantises, and collect wasps' nests. Because most insects either die or enter dormancy in winter, that is a season without *mushi*.

Once a year, in autumn, *suzumushi* (bell crickets) and *kirigirisu* (singing grasshoppers) are offered for

sale in nearly every post office in Japan and sent all over the country in special packages. When summer arrives in rural areas, many village shops feature butterfly nets, rhinoceros beetle cages, and packs of soft humus "mattresses" for keeping stag beetles. Department stores in larger towns and cities, however, remain the best places to buy *mushi*. Their summer displays feature live *mushi*, along with breeding and catching equipment, side by side with various insecticides. Revenue from sales of *mushi* alone climbed to 5 billion yen in 1992.

From spring to autumn, *minmin* cicadas are perhaps the most often caught *mushi* in Japan. Living everywhere—even in the centers of cities, clinging to tree trunks or to walls—they are not difficult prey for tree-climbing children armed with nets and cages. Seemingly of great interest to these children are the cries cicadas make when caught, as well as the tricks used for catching them.

Tombo tori (dragonfly catching) dates back to the first half of the eighteenth century. Dragonflies can

Mushi *introduce children to biological diversity, mortality, and the progression of the seasons.*

be caught by hand or with a net, but the traditional way of catching them is with a tool called a *buri* in western Japan or a *toriko* in Tokyo. Similar to a miniature bola, it is made of two small balls, stones, or shells wrapped in red cloth or paper and tied to a silk thread. The *toriko* is hurled about three feet ahead of the dragonfly, which then flies right into it; the thread becomes tangled in the insect's wings, and the dragonfly falls to the ground. Although popular until the 1960s among boys in the Japanese countryside, catching dragonflies no longer interests most children today. A related activity—catching fireflies—is not as easy as it used to be, because the species is now officially protected and its catchers may be fined.

Spider fighting, too, was very popular until about thirty years ago but is no longer in vogue. In Yokohama in the 1930s, all the twelve-year-old boys used to own spiders. They made the creatures fight by throwing one spider into another's web or by putting two spiders together in a miniature arena fenced in by wood chips. The fights were allowed to continue until one of the arachnids was killed.

Japanese children gain a great deal from their involvement with *mushi*. Among other things, they develop a feeling for the seasons, a sensibility pervasive in Japanese culture. They learn very early, for instance, that fireflies, rhinoceros beetles, and other creatures appear and then die during a limited period of the year. *Mushi* give children concrete material for their experimental dialogue with nature and introduce them to biological diversity. An insect's relatively short life span also teaches them about ontogenetic development and the cycles of life. Feeding and keeping *mushi* requires personal observation, reflection, and even experimentation. A post office leaflet that advertises the selling of *suzumushi* crickets tells children: "While observing, let's write a diary with pictures!" *Mushi* are usually looked after every day by the child, who keeps them until they die.

Traditionally the transmission of knowledge concerning *mushi* used to occur orally, passed from grandfather to grandchild. Although the traditions

YOHEI NAKAMOTO; NATURE PRODUCTION

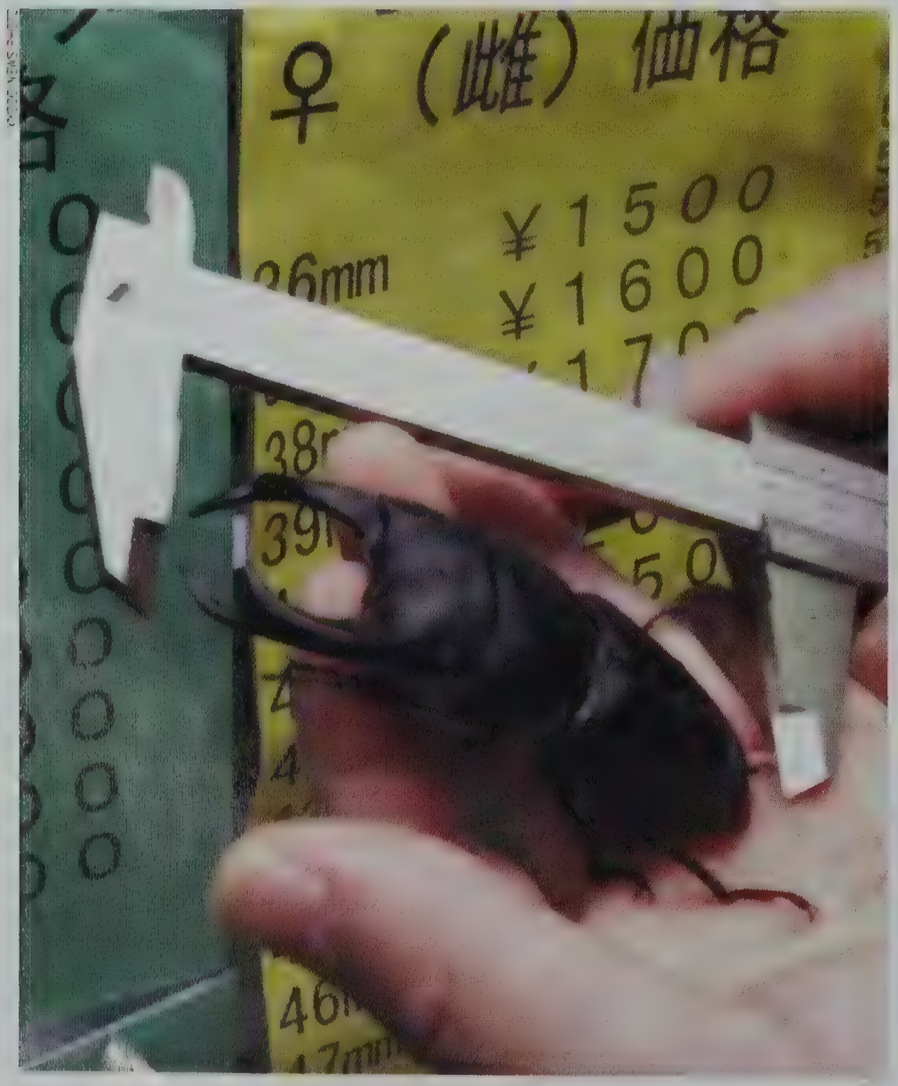
Containers in a *mushi* store, left, are filled with beetle larvae for sale. Below: Boys buy beetles from an automatic vending machine.

KYODO NEWS PHOTO

KAZUO UNNO; NATURE PRODUCTION

A youngster stages a fight between a rhinoceros beetle and a stag beetle.

A boy allows his rhinoceros beetle to walk up his arm, right. Below: A stag beetle more than three inches long was bought for $90,000 by a Tokyo shop in 1999. The record-size beetle drew thousands of young *mushi* enthusiasts into the store.



surrounding *mushi* could easily have been forgotten in modern industrialized Japan, insects have instead been turned into media phenomena, with stories featuring slick, *mushi*-related gear, games, and books. In addition, Japan's contemporary craze for little "virtual" animals that mimic *mushi* constitutes a technological transformation of real animals into "animaltronics." *Tamagochi,* for instance, are electronic toys that metamorphose into various shapes and even "die" if they are not cared for. Understanding growth and change is central to the manipulation of *tamagochi.* For Japanese children, creatures that undergo metamorphosis are a source of fascina-

tion that is culturally reinforced. Pokémon toys are based on characters that continually change into other forms. ("Pokémon," of course, is "Japlish" for "pocket monster"—a computer toy, cartoon, television, and movie craze that has jumped cross-culturally to the West.) The very idea of imagining pocket-sized monsters, or bird-egg-sized pets like *tamagochi,* seems to be connected with the Japanese delight in miniatures, whether bonsai trees, computer chips, or *mushi*. Some of the body forms of Pokémon are clearly based on those of insects. The most obvious example is Caterpie, which resembles a caterpillar, then changes into Metapod, and finally becomes Butterfree. And much more so than any other group of animals, insects appear as secondary characters or as part of the scenery in the television and comic-book versions of Pokémon stories.

Despite the overwhelming mass-market success of these electronic and cartoon "insectoids," however, a sizable number of Japanese children continue to spend time with the genuine article. The fact that the many traditions associated with *mushi* have managed to survive in such a competitive market shows their remarkable vitality and the valued role of these diminutive ambassadors of nature in the education of children in Japan. □

Youngsters combing the fields with their insect nets are a sure sign of spring in rural Japan.

AT THE MUSEUM

The *Helicoprion* Mystery

Where were the teeth situated on this ancient shark? In its jaw? On its tail? On its back?

By Richard Ellis

ROD MICKENS; AMNH

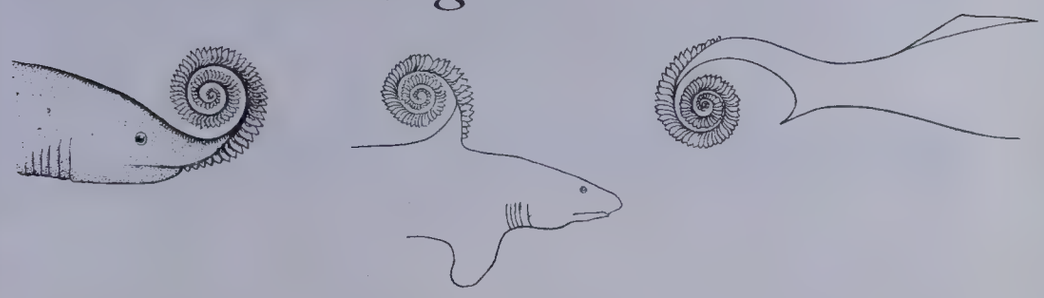
***Helicoprion* fossil**

As painted by Ray Troll, *Helicoprion*'s tooth whorl may have been located on the lower jaw.

In the Museum's Hall of Vertebrate Origins is a most intriguing object, tucked away where few people see it. The object appears to be a perfect spiral of teeth, and the label below it reads, "What is this fossil?" This seems a curious question to be asking of Museum visitors, but the label provides the answer: "Many isolated tooth whorls of *Helicoprion* have been found, such as this specimen, but complete fossil skeletons are unknown." The specimen came from a phosphate mine in Idaho, but others like it have been unearthed in Wyoming as well as in Norway, Russia, Japan, Greenland, and Australia. Paleoichthyologists have categorized the teeth as sharklike and therefore identified the specimen as having belonged to certain primitive cartilaginous fishes—a group that includes the sharks and chimaeras living some 300 million years ago.

Helico- comes from the Greek for "spiral" or "whorl," and *-prion* from the Greek for "saw." *Helicoprion* thus means "spiral saw." But what was this saw used for? Russian paleontologist A. P. Karpinsky was the first to find and describe a specimen, which he collected in 1899 in the Ural Mountains. He puzzled over where to place it on the shark—the lower jaw, the upper jaw, both jaws, the tail, the dorsal fin, the middle of the back? Only a year after Karpinsky's de-

Positioning the Whorl



Above: Paleontologist A. P. Karpinsky found the first specimen of *Helicoprion*'s tooth whorl in 1899, but he could not decide where it might fit on the shark. Almost a century later, Australian paleontologist John A. Long visualized a seemingly extensible apparatus, illustrated below by Ivy Rutzky, of the Museum's Division of Paleontology.

scription appeared in print, American paleontologist C. R. Eastman wrote: "Of the two leading theories as to the position of . . . 'spines,' the first ascribes them to the jaws of a shark or skate, and the other to the median line of the back, some distance in advance of the dorsal fin." In a 1952 analysis of the tooth whorl, Russian paleoichthyologist Dimitri Obruchev decided that a location in the lower jaw "would only prevent the fish from feeding." He therefore placed the whorl in the upper jaw, "where it could serve as effective protection," acting as a shock absorber for the animal's head.

In his 1995 book *The Rise of Fishes: 500 Million Years of Evolution*, John A. Long, curator of vertebrate paleontology at the Western Australian Museum in Perth, includes a hypothetical illustration of *Helicoprion* that shows the shark's lower jaw curling downward into a tooth-studded spiral. One could imagine that the shark uncoiled its jaw and lashed at prey with a sort of toothed whip. Another theory is that *Helicoprion*'s tooth spiral mimicked coiled shellfish called ammonites (especially abundant at the time) in order to attract these ammonites, the shark's prey. "It seems more likely," Long writes, "that these sharks used the jagged tooth-whorls when charging into a school of fish or ammonites and thrashing about to snag prey on the projecting array of teeth."

Richard Lund, a paleoichthyologist at Adelphi University and an expert on sharks from the Devonian Period, points out two of *Helicoprion*'s radical features: the disproportionate size of the teeth making up the whorl, and the bases of the teeth being locked together during growth, a feature that prevented the shedding of the teeth. "Thus the smaller and older teeth are just shoved out and down, sort of like an ingrown toenail, only with teeth." Lund also believes the spiral must have been proportional to the size of the jaw that supported it: "Any reconstruction of the fish itself must be big enough to accommodate, smoothly, a buzz-saw-like gadget that got up to three feet in diameter. This yields a fish of very impressive size as well as impressive dentures."

A veritable cottage industry is devoted to the solution of the *Helicoprion* tooth-whorl mystery, and the tenor of some of the publications it inspires is unmistakably tongue-in-cheek. In the April 1, 1973—note the date—issue of the *Journal of Insignificant Research*, paleontologists Michael Williams and Kathy Elbaum, quoting from a 1966 paper by Danish paleontologist Svend Erik Bendix-Almgreen ("On the Significance of Karpinsky's Reconstruction") demonstrate that *Helicoprion*'s

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whorl was the biomechanical equivalent of a New Year's Eve noisemaker. It could be extended by hydraulic force, releasing "in effect a lethal raspberry."

In their 1994 book *Planet Ocean: A Story of Life, the Sea, and Dancing to the Fossil Record,* author Brad Matsen and artist Ray Troll devote an entire page to the "vexing fossil shark." Troll admits to an obsession with *Helicoprion*'s tooth whorl, and he recently made a model of it. "There was no upper-half whorl of sharp teeth for the whorl to cut against," says Troll, "only rows of small crushing teeth. In all of the whorls and skulls Bendix-Almgreen examined, no other upper teeth were found besides the crushing teeth. . . . I could begin to 'see' the outline of the skull: long and extremely narrow. I realized this thing had a long nose on it much like a modern-day goblin shark. . . . As it grew, it produced bigger teeth, so what you're seeing is really a fossilized growth ring." Troll has drawn a new version of *Helicoprion,* but like all such reconstructions, whether by artists or paleontologists, it is at best an educated guess. *Helicoprion*'s secrets are still locked in the 280-million-year-old rocks.

Marine expert Richard Ellis's latest book is Encyclopedia of the Sea *(Knopf, 2000).*

MUSEUM EVENTS

MARCH 1
Lecture: "Impact of Global Warming on Polar Bears and Tundra Ecosystems" (Earthwatch at the Museum series). Ecologist Peter Scott, of the Churchill Northern Studies Centre. 7:00 P.M., Kaufmann Theater.

MARCH 5
Lecture: "Quasar Absorption Lines: Seeing Ghosts in the Universe" (Frontiers in Astrophysics series). Astronomer Jane Charlton. 7:30 P.M., Space Theater, Hayden Planetarium.

MARCH 5, 12, 19, AND 26
Four lectures: Biodiversity and Seaside Plants series. William Schiller, Museum botany lecturer. 2:30 P.M., Kaufmann Theater. (The series is repeated on four consecutive Thursdays at 7:00 P.M., starting March 8.)

MARCH 7
Preview clips and panel discussion: *Land of the Mammoth,* Discovery Channel's second documentary about the Jarkov mammoth and other Ice Age species in Siberia. 7:00 P.M., IMAX Theater.

MARCH 7, 14, AND 21
Three lectures: "Nonzero: The Logic of Human Destiny," science writer Robert Wright, March 7; "The History of Time," Museum astrophysicist Charles Liu, March 14; "Ecology and History of the Hudson River," Museum ecologist Jay Holmes, March 21 (Natural History and Life: AARP series). 2:00 P.M., Kaufmann Theater.

MARCH 8, 15, AND 22
Three lectures: Geology of the Revolutionary War in Metropolitan New York series. Geologist Sidney S. Horenstein, coordinator of the Museum's environmental public programs. 7:00 P.M., Kaufmann Theater.

D. FINNIN; AMNH

Chinese sundial, from exhibition of historical instruments at Weston Pavilion entrance, Columbus Avenue

MARCH 13
71st James Arthur Lecture on the Evolution of the Human Brain: "Evolution of Neocortex: Lessons From Embryo-Archaeology." Neurobiologist Pasko Rakic, of the Yale University School of Medicine. 6:00 P.M., Kaufmann Theater.

MARCH 19
Lecture: "The 23rd Cycle: Learning To Live With a Stormy Star" (Distinguished Authors in Astronomy series). Astronomer Sten Odenwald. 7:30 P.M., Space Theater, Hayden Planetarium.

DURING MARCH
International Women's History Month: "Everyday Heroines." Free weekend films, lectures, performances, and workshops. 1:00–5:00 P.M., March 3–18, Leonhardt People Center. For information, call (212) 769-5315.

Symposium registration: "Conservation Genetics in the Age of Genomics." April 4 keynote speaker: author and activist Jeremy Rifkin. April 5–6: scientific presentations. Sponsored by the Museum's Center for Biodiversity and Conservation and the Bronx Zoo–based Wildlife Conservation Society. Call (212) 769-5200 or visit research.amnh.org/biodiversity/.

Films at the IMAX Theater: *Shackleton's Antarctic Adventure* (the dramatic story of the 1914–17 British Imperial Trans-Antarctic Expedition) and *Ocean Oasis* (the biodiversity of the Baja California peninsula).

The American Museum of Natural History is located at Central Park West and 79th Street in New York City. For listings of events, exhibitions, and hours, call (212) 769-5100 or visit the Museum's Web site at www.amnh.org. Space Show tickets, retail products, and Museum memberships are also available online.

REVIEW

Cosmic Chemists

Gazing out at the far reaches of the universe led scientists back into the microworld of matter.

By Martin J. Rees

NASA AND THE HUBBLE HERITAGE TEAM (STSCI/AURA)

The unity of nature isn't just a poetic phrase. Ever since Isaac Newton showed that the same gravitational force that pins us to Earth holds the planets in their orbits, we have become more mindful that cosmos and microworld are intricately linked.

Science writer Marcus Chown expresses this theme beautifully. He recounts how scientists had to understand atoms before they could understand what made the stars shine, and how this led to the realization that the atoms on Earth were themselves forged in ancient stars. In tracing this intellectual quest, Chown highlights the advances made by many important but underappreciated pioneers in the field.

French philosopher Auguste Comte famously averred in 1835 that while we might learn the sizes and motions of stars, we would never know what they are made of. Within twenty years, Comte would be proved wrong. German chemist Robert Bunsen and a compatriot, physicist Gustav Kirchhoff, showed that dark lines previously discovered in sunlight's spectrum were caused by elements such as sodium, whose glowing emissions could be analyzed in the laboratory. Later, English amateur astronomer William Huggins, using newly available photographic techniques, found that the much fainter spectra of stars displayed the same line patterns as those of the solar spectrum. The Sun, Earth, and stars were made of the same stuff.

The Magic Furnace: The Search for the Origins of Atoms, *by Marcus Chown (Oxford University Press, 2001; $25)*

All this was achieved before atoms were understood. Indeed, until 1900 the reality of atoms was in serious doubt, despite compelling indirect arguments that the building blocks of matter came in discrete units. Stellar spectra had revealed the "bar codes" of many different elements. But since there is no straightforward relation between the strength of a spectral feature and the abundance of the element that causes it, twentieth-century physics would be needed to clarify the situation. Indeed, until the 1920s it wasn't appreciated that hydrogen and helium—the two lightest elements—were overwhelmingly the most abundant. Much credit here goes to British astronomer Cecilia Payne, whose 1925 Ph.D. thesis at Radcliffe College presented evidence that these two elements amount to 98 percent of the mass of the Sun. Sadly, the skepticism of the influential astrophysicist Henry Norris Russell led her to downplay what was actually her greatest discovery and to declare in a journal article that this inferred abundance of both hydrogen and helium in stars was "improbably high and is almost certainly not real."

Another mystery was what kept the Sun and stars shining. Nineteenth-century geologists, basing their estimate on sedimentary rock strata, gauged Earth's age to be hundreds of millions of years. Charles Darwin, in proposing his ideas about natural selection, concurred with the estimate, while England's leading physicist, William Thomson (Lord Kelvin), dogmatically argued that the Sun could not have been shining for much longer than 10 million years. U.S. geologist Thomas Chamberlain responded—in words that should resonate with some of today's theorists—that "there is perhaps no beguilement more insidious and dangerous than an elaborate and elegant mathematical process built upon unfortified premises." A detailed understanding of the reactions that have allowed the Sun to shine for 4.5 billion years as a "gravitationally confined fusion reactor" didn't come about until the late 1930s, through the insights of two U.S. physicists, Russian-born George Gamow and German-born Hans Bethe, and those of German physicist and philosopher Friedrich Carl von Weizsäcker.

If nuclei can fuse inside stars, could the entire periodic table of 92 elements be the outcome of nuclear transmutations in stars? Beginning in the mid-1940s, British astronomer Fred Hoyle was the dominant figure promulgating this idea. The most efficient processing occurs in heavy stars, which shine more brightly than the Sun and burn their hydrogen more rapidly. Gravity then squeezes them further, and the centers get still hotter, until the helium nuclei fuse into the nuclei of heavier atoms. When all their fuel has been consumed, big stars face a catastrophic collapse that can compress their cores to a state 1,000,000,000,000,000 times denser than an ordinary solid, trans-

forming them into neutron stars or perhaps black holes.

But this collapse also releases enough energy to trigger a colossal explosion—a supernova—that blows off the star's outer layers. These layers have by then developed an onionskin structure. Through nuclear alchemy, hydrogen has burned into helium, helium into carbon, carbon into nitrogen, and so on through the periodic table, up to and including iron—the main element in the core of these doomed stars.

The formation of elements higher up the periodic table requires a further input of energy. Thorium and uranium, for instance, are forged in the heat of a supernova, and barium and bismuth via the capture of neutrons within red giant stars. By 1957 these processes were codified in a classic paper that Hoyle coauthored with U.S. nuclear astrophysicist William Fowler and English astronomers Geoffrey and Margaret Burbidge. Canadian physicist Alastair Cameron developed some key ideas independently.

The galaxy is like an ecosystem. An oxygen atom expelled from a massive star may have wandered for hundreds of millions of years in interstellar space. It may then have found itself in a dense cloud, contracting under its own gravity to make a new star, surrounded by a dusty disk. That star might have been our Sun; that particular atom could have ended up on Earth and perhaps been cycled through a human cell. We are stardust—or the nuclear waste from the fuel that makes stars shine.

This scenario disappointed George Gamow. He thought that all elements emerged from the big bang, but this wasn't borne out by detailed calculations. When Albert Einstein's theory of relativity was used to model an expanding universe, it turned out that the temperature dropped so quickly following the big bang that there was no time for the network of reactions needed to produce all the elements. Moreover, observations showed that younger stars contained more heavy elements than older stars—corroborating the idea that stars formed from interstellar gas that became "polluted" over time. But Gamow was partially vindicated; he proved to be right about the origins of the light elements deuterium, helium, and lithium. Even the oldest stars are 23 percent helium—precisely the proportion that emerges from the big bang.

Seeking the true origins of atoms has been an interdisciplinary quest stretching back more than 200 years. Its pioneers deserve the same acclaim that is rightly given to those who proposed biological evolution. Through their insights, we now view Earth and its constituent atoms in a grand cosmic context. Marcus Chown's fascinating chronicle of their achievements deserves to be widely read.

Keyhole Nebula in Carina

NASA AND THE HUBBLE HERITAGE TEAM (STSCI/AURA)

Martin J. Rees is a Royal Society Professor at the University of Cambridge and England's Astronomer Royal. His most recent book is Just Six Numbers: The Deep Forces That Shape the Universe *(Perseus Press, 1999).*

nature.net

Gems of the Universe

By Robert Anderson

Last month I revisited one of the first Internet sites reviewed in this column, the one created to post the latest images from NASA's Hubble Space Telescope. I was drawn to a wonderful new extension of the site called Hubble Heritage Project (heritage.stsci.edu/index.html).

The project's astronomers have refined the telescope's scientific images by paying close attention to such details as composition and color. While maintaining the accuracy of the originals, the resulting images are far more striking and often reveal details previously hidden from the unaided eye. These spectacular photographs are works of art worthy of their subject—the universe.

In the gallery, you'll find stunning images of everything from planets to merging galaxies. But they are more than just pretty pictures; the purpose of the project is to pique our curiosity about the universe. Each image tells a remarkable story, augmented by lengthy explanations and links to other sites.

My favorite is Planetary Nebula IC 418, a sunlike star that in its death throes became a red giant and then ejected its outer layers into space, forming the nebula. The stellar remnant at its core floods the surrounding gas with ultraviolet radiation, causing it to fluoresce, "glowing like a multifaceted jewel."

But they are all gems. Take NGC 3314, a spiral galaxy pair. The two are aligned so that one is silhouetted against the other, giving us the rare chance to view the light-absorbing dust clouds darkening the spiral arms of a distant galaxy. Or how about Galaxy M87 (NGC 4486), with its bluish jet of electrons and other subatomic particles streaming from the black hole at its center? Every image is magnificent.

Robert Anderson is a freelance science writer living in Los Angeles.

BOOKSHELF

The 23rd Cycle: Learning To Live With a Stormy Star, *by Sten Odenwald (Columbia University Press, 2001; $27.95)*
Tracing the recent history of the Sun's destructive power, astronomer Odenwald warns us about the coming cycle of solar flares and storms, which may cause blackouts, satellite malfunctions, and other kinds of havoc.

Cosmic Evolution: The Rise of Complexity in Nature, *by Eric Chaisson (Harvard University Press, 2001; $27.95)*
"From galaxies to snowflakes," writes astrophysicist Chaisson, "from stars and planets to life itself, we are beginning to identify an underlying, ubiquitous pattern penetrating the fabric of all the natural sciences."

The Neptune File: A Story of Astronomical Rivalry and the Pioneers of Planet Hunting, *by Tom Standage (Walker, 2000; $24)*
Neptune was "discovered" in 1845 by mathematical calculation (not with a telescope), setting a precedent for a method of extrasolar planet hunting that has, to date, turned up more than forty.

Spacefaring: The Human Dimension, *by Albert A. Harrison (University of California Press, 2001; $27.50)*
A psychologist offers an overview of humans in space, covering such topics as motives for leaving Earth, group dynamics, and habitability of spacecraft.

Designs on Space: Blueprints for 21st Century Space Exploration, *by Richard Wagner, illustrated by Howard Cook (Simon & Schuster, 2001; $24)*
Elucidating blueprints for rockets, robotic arms, solar sails, and the $30 billion International Space Station, science writer Wagner shows us the equipment we'll be using to investigate the neighborhood of planet Earth.

A Thin Cosmic Rain: Particles From Outer Space, *by Michael W. Friedlander (Harvard University Press, 2000; $29.95)*
A physicist explains the phenomenon of cosmic rays and reveals what they tell us about the universe, the solar system, and Earth, as well as their role in the discovery of subnuclear particles.

Stardust: Supernovae and Life—The Cosmic Connection, *by John Gribbin with Mary Gribbin (Yale University Press, 2000; $24.95)*
The Gribbins discuss the formation of chemical elements—how they are processed inside stars, scattered across the universe in great stellar explosions, and recycled to become new stars, planets, and parts of ourselves.

Einstein's Unfinished Symphony: Listening to the Sounds of Space-Time, *by Marcia Bartusiak (Joseph Henry Press, 2000; $24.95)*
Science writer Bartusiak explains how sophisticated instruments allow scientists to hear gravity waves—vibrations in space-time first postulated by Einstein.

The books mentioned are usually available in the Museum Shop, (212) 769-5150, or via the Museum's Web site, www.amnh.org.

UNIVERSE

Coming to Our Senses

By Neil de Grasse Tyson

Equipped with his five senses, man explores the universe around him and calls the adventure science.

—Edwin P. Hubble, 1948

Our eyes are special organs. They allow us to register information not only from across the room but from across the universe. Without human eyesight, the science of astronomy would never have been born, and our capacity to measure our place in the universe would have been hopelessly stunted. Think of bats. Whatever bat wisdom gets passed from one generation to the next, you can bet that none of it is based on the appearance of the night sky.

When thought of as an ensemble of experimental tools for exploring the world, our senses have an astonishing acuity and range of sensitivity: Your ears can register the thunderous launch of the space shuttle, yet they can also hear a mosquito buzzing a foot away from your head. Your sense of touch allows you to feel not only a bowling ball dropped on your big toe but also a one-milligram bug crawling up your arm. Some people enjoy munching on habanero peppers, while other people can taste (and rebel against) the habanero on the level of parts per trillion. And your eyes can register the bright, sandy terrain on a sunny beach yet have no trouble spotting a lone match, freshly lit, hundreds of feet away in a darkened auditorium.

Before we get carried away in praise of ourselves, note that we gain in breadth what we lose in precision, because we register the world's stimuli in logarithmic rather than linear increments. For example, if you increase a sound's energy by a factor of two, you will barely take notice. Increase it by a factor of ten, and the change will be apparent. Our eyes perceive light the same way. If you have ever viewed a total solar eclipse, you may have noticed that the Sun's disk must be at least 90 percent covered by the Moon before anybody comments that the sky has darkened. The magnitude scale of stellar brightness, the well-known acoustic decibel scale, the seismic scale for earthquake severity—each is logarithmic, in part because of our biological propensity to see, hear, and feel the world that way.

What, if anything, lies beyond our senses? Does there exist a way of knowing that isn't limited by these bi-

ological connections with our earthly environment?

Consider that the human machine, while good at decoding the basics of the immediate environment (if it's day or night, if a creature is about to eat us), has very little talent for decoding how the rest of nature works. For that, we need the tools of science. If we want to know what's out there, then we must resort to detectors other than the ones we are born with. The job is to extend and, when we can, transcend the breadth and depth of our senses.

Some people boast of having a sixth sense, professing to know or see things that others cannot. Fortune-tellers, mind readers, and mystics top the list of those who lay claim to these mysterious powers. In so doing, they elicit widespread fascination in others, especially book publishers and television producers. The questionable field of parapsychology is founded on the belief that at least some people actually possess this talent. To me, the biggest mystery of all is why so many fortune-tellers choose to work the phones on TV psychic hotlines instead of becoming insanely wealthy futures traders on Wall Street. Apart from this inexplicable fact, the persistent failure of controlled, double-blind experiments to support the claims of parapsychology suggests that what's going on is nonsense rather than sixth sense.

Sacrificing precision for breadth, we register the world's stimuli in logarithmic rather than linear increments.

Modern science wields dozens of "senses," yet scientists do not claim to have special powers, just special hardware. In the end, of course, the hardware converts the information it gleans into simple tables, charts, diagrams, or images that our innate senses can interpret. In the original *Star Trek* sci-fi series, the crew that beamed down from their starship to an uncharted planet always brought with them a "tricorder," a handheld device that could analyze the basic properties of anything they encountered, living or inanimate. As you waved the tricorder over the object in question, it made a spacey sound that was interpreted by the user.

Suppose a glowing blob of some unknown substance were parked right in front of you. Without some diagnostic tool like a tricorder, you would be clueless about the blob's chemical or nuclear composition. Nor could you know whether it has an electromagnetic field or whether it is strongly emitting gamma rays, X rays, ultraviolet radiation, microwaves, or radio waves. If the blob were far out in space, appearing as an unresolved point of light in the sky, your five senses would offer no hint of its distance, its velocity through space, or its rate of rotation. You would have no capacity to see the spectrum of colors that compose its emitted light, nor could you know (as bees do) whether or not the light was polarized. Without any hardware to help your analysis—and lacking the urge to lick the stuff—all you could report back to the starship would be, "Captain, it's a blob."

Apologies to Edwin P. Hubble, but his words at the top of this essay, while poignant and poetic, should have read more like this:

> *Equipped with our five senses—along with telescopes and microscopes and mass spectrometers and seismographs and magnetometers and particle accelerators and detectors sensitive to the entire electromagnetic spectrum—we explore the universe around us and call the adventure science.*

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Imagine how much richer the world would appear to us and how much earlier the nature of the universe would have been figured out if we were born with high-precision, tunable eyeballs: Tune into the radio-wave part of the spectrum, and the daytime sky is as dark as night, except in some choice locations, such as the center of our galaxy (visible behind some of the principal stars of the constellation Sagittarius). Dial up microwaves, and the entire cosmos is aglow with a remnant from the early universe, a wall of light that hails from 300,000 years after the big bang. Flip the dial to X rays, and the locations of nearby black holes, with matter spiraling into them, pop immediately into view. Tune into gamma rays, and see titanic explosions scattered throughout the universe at a rate of about one per day. Watch the effect of these explosions on the surrounding material as it heats up and glows in other bands of light.

Our senses, honed from infancy, allow us as adults to pass judgment on events and phenomena in our lives, telling us whether or not they "make sense."

If we were born with magnetic detectors, the compass would never have been invented, because we wouldn't need one. We could just tune into Earth's magnetic field lines (as some bacteria do), and the magnetic north pole would call to us from beyond the horizon. If we had gas analyzers within our retinas, we wouldn't have to wonder what was in the air we were breathing. We could just check the analyzer to see whether the air contained sufficient oxygen to sustain human life. And we would have learned thousands of years ago that the stars in the Milky Way contain the same chemical elements found here on Earth.

If we were born with big eyes and built-in Doppler motion detectors, we would have seen immediately, even as grunting troglodytes, that all distant galaxies are receding from us—that the entire universe is expanding.

If our eyes had the resolution of high-performance microscopes, nobody would ever have blamed the plague and other illnesses on divine wrath. The bacteria and viruses that make us sick would be in plain view as they crawled on our food or slid through open wounds on our skin. With simple experiments, we could easily tell which bugs were bad and which were good. And, of course, the problem of postoperative infection would have been identified and solved hundreds of years earlier.

If we could detect high-energy particles, we would be able to spot radioactive substances from great distances—no Geiger counters necessary. You could even watch radon gas seep through the basement floor of your home and not have to pay somebody to tell you about it.

Honed from infancy, our senses allow us as adults to pass judgment on events and phenomena in our lives, to determine whether or not they "make sense." Problem is, hardly any scientific discoveries of the past century flowed from the direct application of our five senses. They flowed instead from sense-transcendent mathematics and hardware. This simple fact explains why relativity, particle physics, and ten-dimensional string theory make no sense to the average person. Neither do black holes, wormholes, and the big bang. Actually, these things don't make much sense to scientists either. At least not until they acquire a new and higher level of "common sense" from long study of the math and physics of the universe. This

allows for creative thinking and enables us to pass judgment in the unfamiliar underworld of the atom or in the mind-bending domain of higher-dimensional space. The German physicist Max Planck, who won a Nobel Prize in 1918, made a similar observation about the discovery of quantum mechanics:

> *Modern Physics impresses us particularly with the truth of the old doctrine which teaches that there are realities existing apart from our sense-perceptions, and that there are problems and conflicts where these realities are of greater value for us than the richest treasures of the world of experience.*

Our five senses even interfere with sensible answers to stupid metaphysical questions, such as "If a tree falls in the forest and nobody is around to hear it, did it fall?" My best answer is, "How do you know it fell?" But that just gets people angry. So I offer a senseless analogy: "Q: If you can't smell the carbon monoxide, how do you know it's there? A: You drop dead." (Natural gas, too, is odorless to the human nose. For our protection, a pungent smell is added so that gas leaks can be safely identified and located.) In modern times, if the sole measure of what's out there flows from your senses, then a precarious life awaits you.

New ways of knowing are new windows on the universe, new detectors we can add to our growing list of nonbiological senses. Whenever this happens, a new level of majesty and complexity in the universe reveals itself to us, as though we were technologically evolving into supersentient beings, always coming to our senses.

Neil de Grasse Tyson is the Frederick P. Rose Director of New York City's Hayden Planetarium. This semester he is teaching astrophysics at Princeton University.

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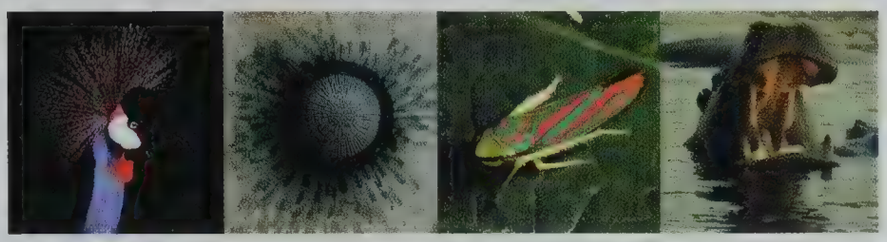

AMNH Photos: Crane by Frank Puzo; Porpita by B. Hunter; Leaf Hopper by B.J. Kaston. Copyright © Natural History Magazine, 1999

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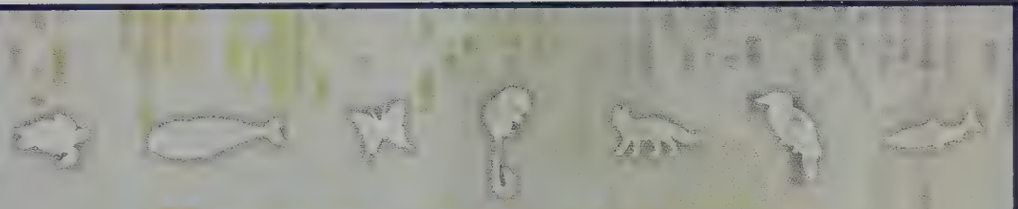

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THE NATURAL MOMENT

Photograph by James Warwick

Pier Revue

Built in 1866, the West Pier at Brighton, on the south coast of England, has long been a place for socializing. Seaside visitors flocked to its pavilion and concert hall until the pier closed in 1975. Although the empty buildings on the now derelict structure are silent by day, they come noisily alive on winter nights with the chirps, whistles, and varied murmurings of starlings—tens of thousands of them. As their natural roosts in woods and reed beds become scarce, starlings, which seek safety in numbers, readily adapt to buildings and bridges. Photographer James Warwick, himself a Brighton native, notes that small flocks from miles around arrive each evening, then coalesce into a huge roosting congregation. Before settling in for the night, the starlings indulge in an almost silent aerial display. One can hear only their "wings ripping the air" as they change direction en masse, like "iron filings in a magnetized sky."—*Judy Rice*

DANGEROUS STRUCTURE
KEEP OFF

ENDPAPER

Informed Consent

A muckraking book spotlights the ethics of anthropological fieldwork.

By Samuel M. Wilson

Early last September, an ominous message addressed to the president of the American Anthropological Association (AAA) began making the rounds of the e-mail grapevine. "We write to inform you," it began, "of an impending scandal that will affect the American anthropological profession as a whole in the eyes of the public, and arouse intense indignation and calls for action among members of the Association." Prompting this warning was the imminent publication of *Darkness in El Dorado: How Scientists and Journalists Devastated the Amazon* (W. W. Norton). The book's author, freelance journalist Patrick Tierney, was charging anthropologists and other outsiders who worked in Amazonia in the 1960s with a wide range of misdeeds and ethical violations, the most horrifying of which was that they had intentionally introduced a devastating measles epidemic among the Yanomami. One of those singled out was Napoleon A. Chagnon, who published a vivid account of his fieldwork, "Yanomamö—The Fierce People," in *Natural History* way back in January 1967.

CHRIS STEELE-PERKINS; MAGNUM

Yanomami, 1989

When news of the book first hit, the reaction of many anthropologists was a quiet dread that it represented only the start of an unpleasant airing of the profession's less defensible acts and practices in the past. Anthropology emerged late in the nineteenth century, when many traditional societies were vanishing or being forever changed by colonial expansion and modernization. Anthropologists felt it was their mission to record what remained of the languages, knowledge, and worldviews of disintegrating cultures. They did not necessarily pause to consider that their presence in the field or the dissemination of the knowledge they gained might harm the people they studied. In fact, their work often aided colonial administrators and occasionally served as a cover for espionage.

By the 1960s, anthropologists had begun to agonize over their ability to be impartial observers. With the social upheavals of the Vietnam War, the belief that science was politically neutral came sharply into question. When some social scientists provided cultural information in support of the U.S. war effort, they were called to account by members of the AAA. At the same time, a feminist critique of science emerged, challenging long-held, deeply biased interpretations. Ethnographers also reconsidered what they owed their "informants" in terms of shared credit and editorial control over what was being written about them, and reassessed the condescending assumption that they knew what was right for "their" tribe.

Among the results of this soul-searching was that in 1965 the AAA impaneled a Committee on Research Problems and Ethics and, in 1967, adopted a code of ethics. Much amended over the years, the current code includes the following wording: "Anthropological researchers have primary ethical obligations to the people, species, and materials they study and to the people with whom they work. These obligations can supersede the goal of seeking new knowledge."

The claims made in *Darkness in El Dorado* are now being carefully reviewed and debated. The most damning accusations appear to be unsupported or false. Nevertheless, past research among the Yanomami was not ethically untainted, particularly in that acts of violence may have been instigated to study the supposedly violent nature of men. Long before the book's publication, in fact, criticism against some anthropologists was expressed within the field. (Web sites that document the charges and countercharges include www.tamu.edu/anthropology/Neel.html and www.anth.ucsb.edu/chagnon.html.)

The practice of anthropology will always be ethically complex, simply because the researcher is caught between different cultural systems. The *El Dorado* scandal, however, highlights the sea change that has occurred over the past forty years. Although some research from the 1960s and before was of the highest ethical standards and some research being carried out today is still questionable, on the whole the discipline has become more self-aware. And while at one time seeking the "informed consent" of the studied was unknown, proceeding without it now is almost unthinkable.

Samuel M. Wilson is an associate professor of anthropology at the University of Texas at Austin.

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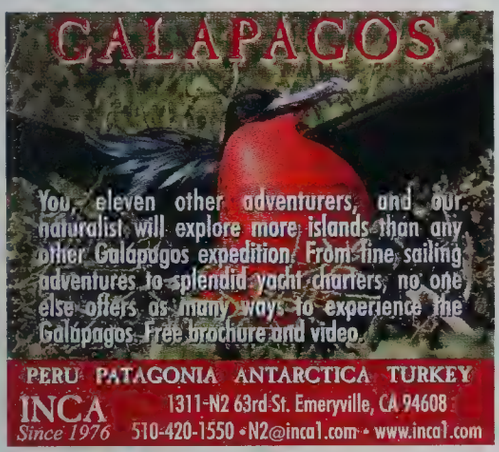

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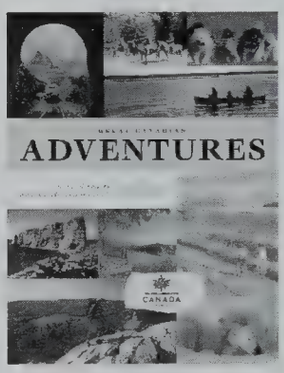

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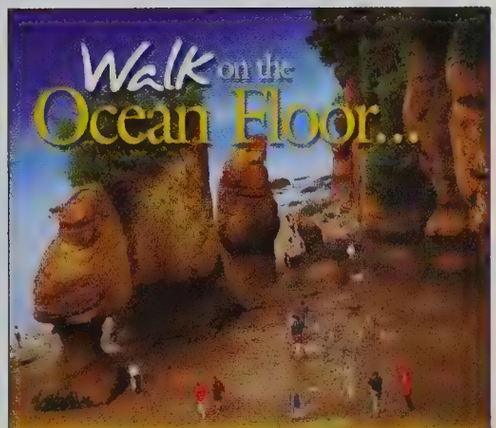

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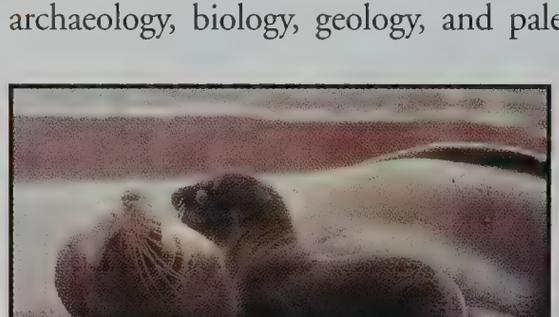

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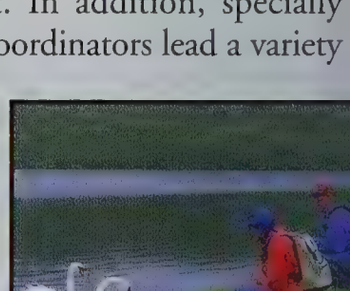

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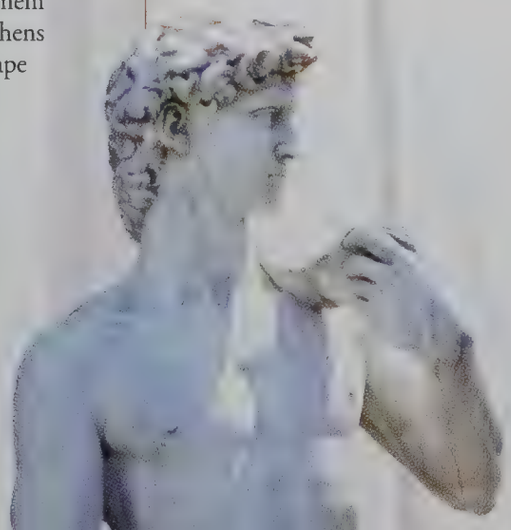

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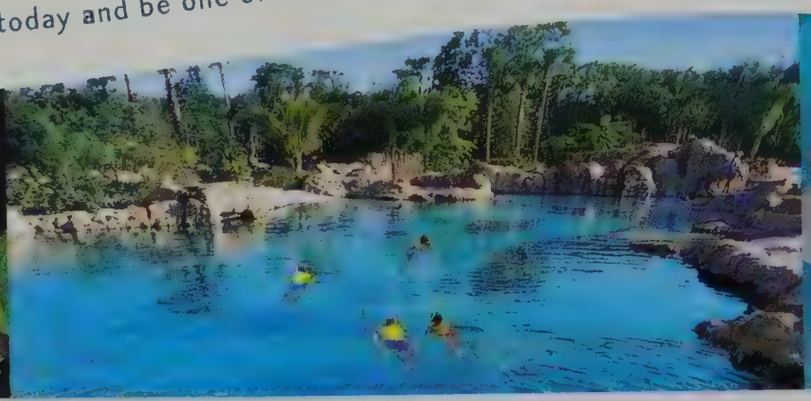

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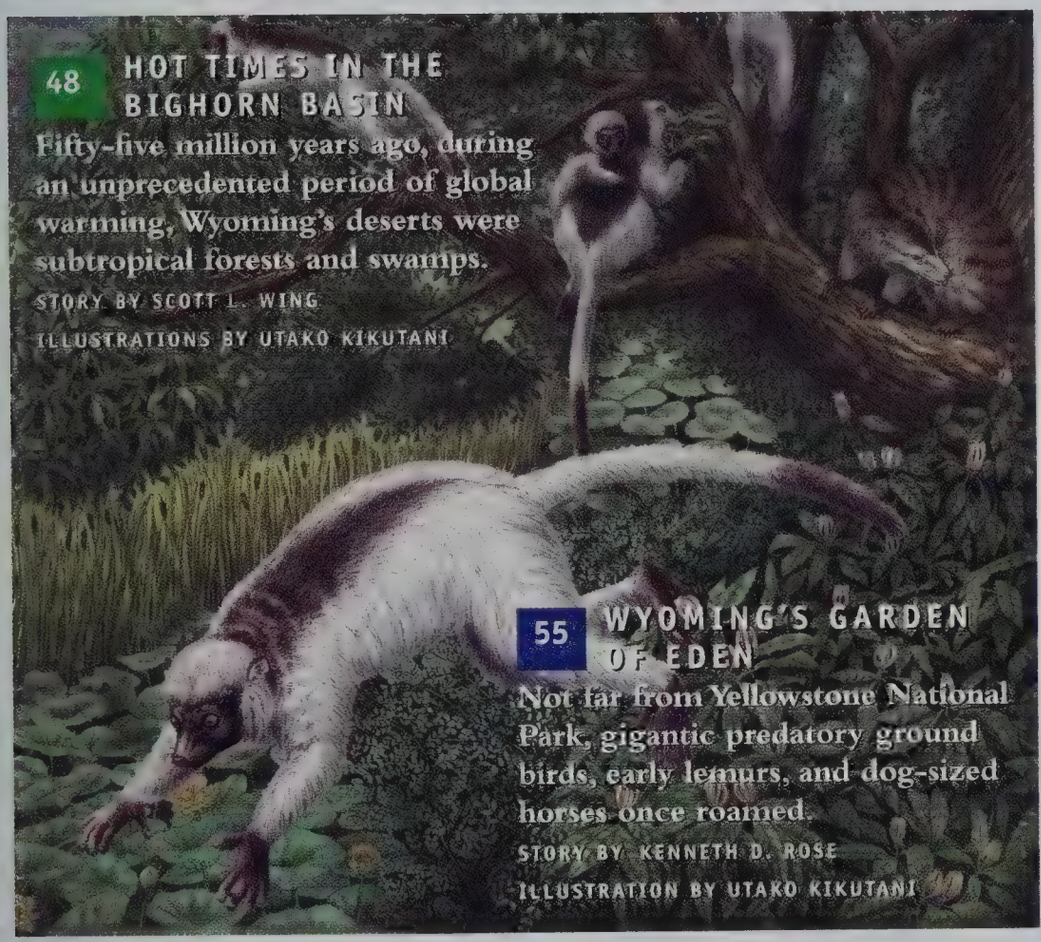

48 HOT TIMES IN THE BIGHORN BASIN
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Growing up in Andean Ecuador, Rosa became accustomed to a life of labor at an early age.
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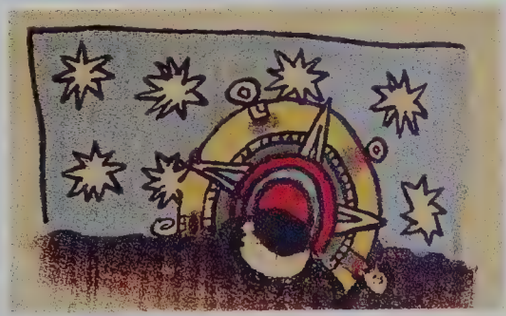

66 OTHER STARS THAN OURS
Aztec priests used their astronomical expertise to devise an elaborate ritual calendar.
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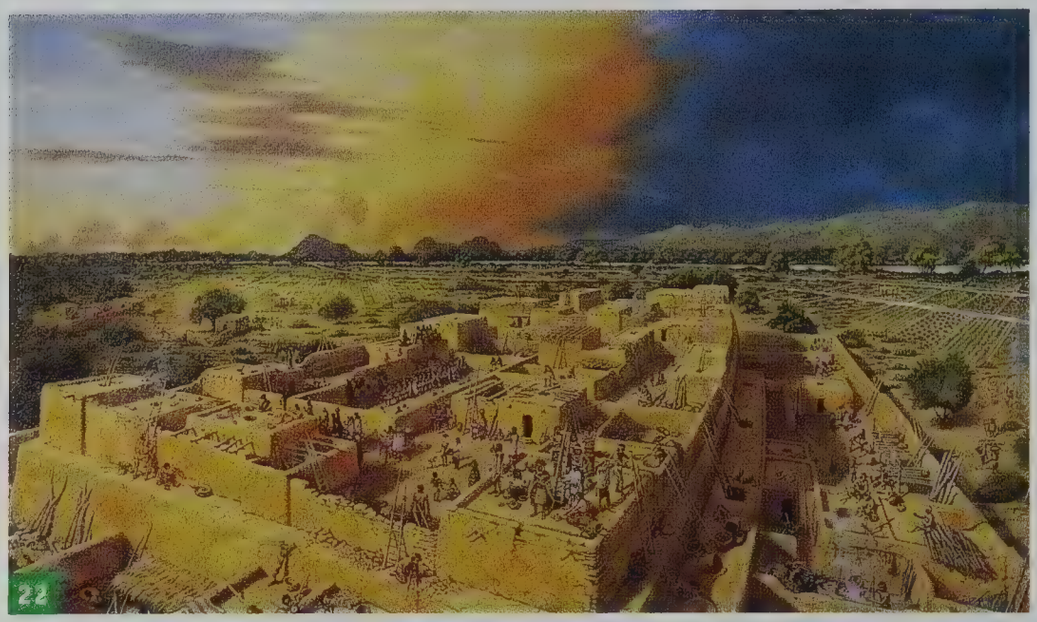

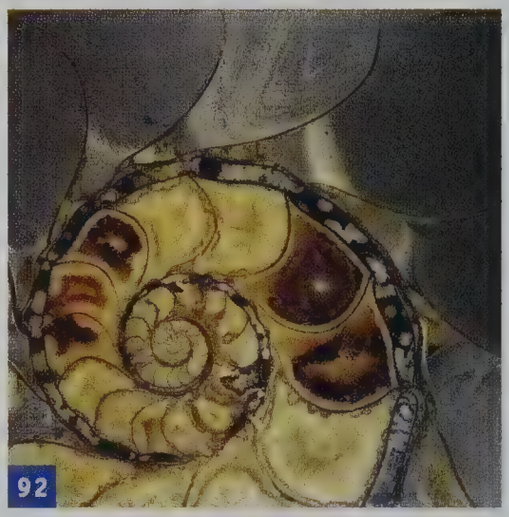

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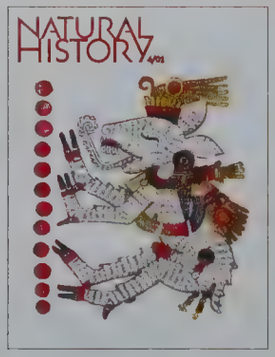

COVER A living deer depicted in the Codex Borgia, an Aztec document, represents half of a 260-day ritual calendar. (The other half is symbolized by a dead deer.)

STORY BEGINS ON PAGE 66

PHOTOGRAPH BY MEGAN CARLOUGH; AMNH

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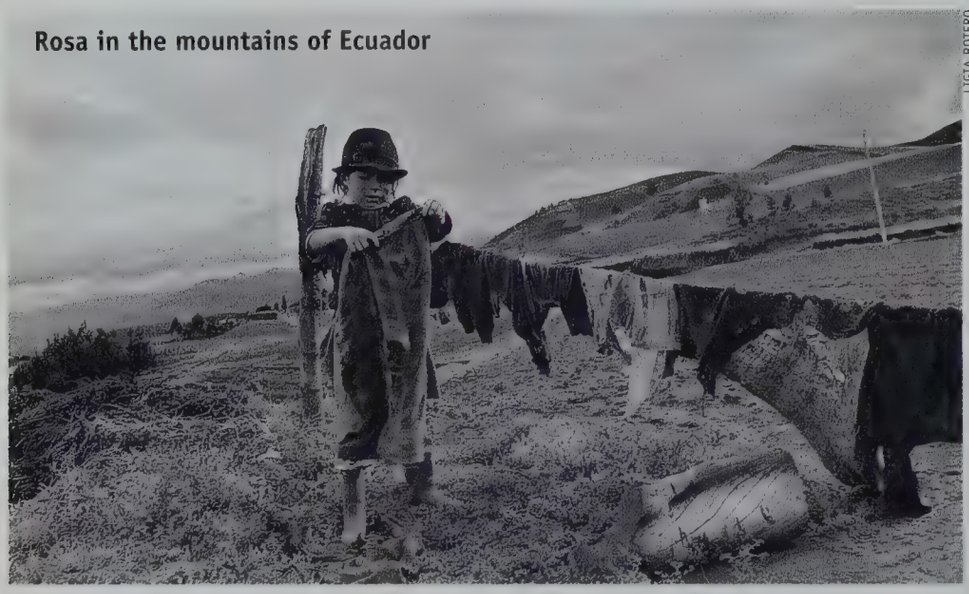
appropriately complex

UP FRONT

One Girl's Life

Surely it is difficult for any of us to understand how someone else experiences the world. Stuck in our own skins, limited to a given time and place in history, we are evolved to be healthily self-absorbed. To appreciate a life lived in another country (or next door, or even in the next room) requires empathic imagination and reason. We also need facts—as well as ideas to help us interpret those facts.

Textbooks, of course, have their limitations, which great works of art and literature help us transcend. Read *Anna Karenina,* and Tolstoy makes you learn—and feel—something of what happened to a woman if she stepped out of line in upper-class nineteenth-century Russian society. Read *The Autobiography of Malcolm X,* and you see the world through the prism of a forceful and specific individual mind, forged in a specific period of



Rosa in the mountains of Ecuador

LIGIA BOTERO

twentieth-century America. But the facts and truths of many other kinds of lives remain unexpressed, either in great novels or in autobiographies.

Enter Ligia Botero, a photographer who believed it was important to document the life of Rosa, an indigenous Ecuadorean girl. And enter Lynn A. Meisch, who, as a cultural anthropologist, can help us understand one another (and therefore ourselves) by teasing apart what is universal and what is particular in the innumerable lives being lived out on this planet.

In "Working Girl" (page 74), Botero and Meisch tell Rosa's story. Hers is the traditional life of any girl born poor in a poor country. But Rosa's life is also a very modern one, its broad contours shaped by global economic forces and its details modified by individual needs and personal enterprise.

Botero's beautiful, thought-provoking images and Meisch's seasoned observations allow us the privilege of traveling a short distance into the difficult life of Rosa—and, one hopes, into a more subtle understanding of the complex world we share with her.—*Ellen Goldensohn*

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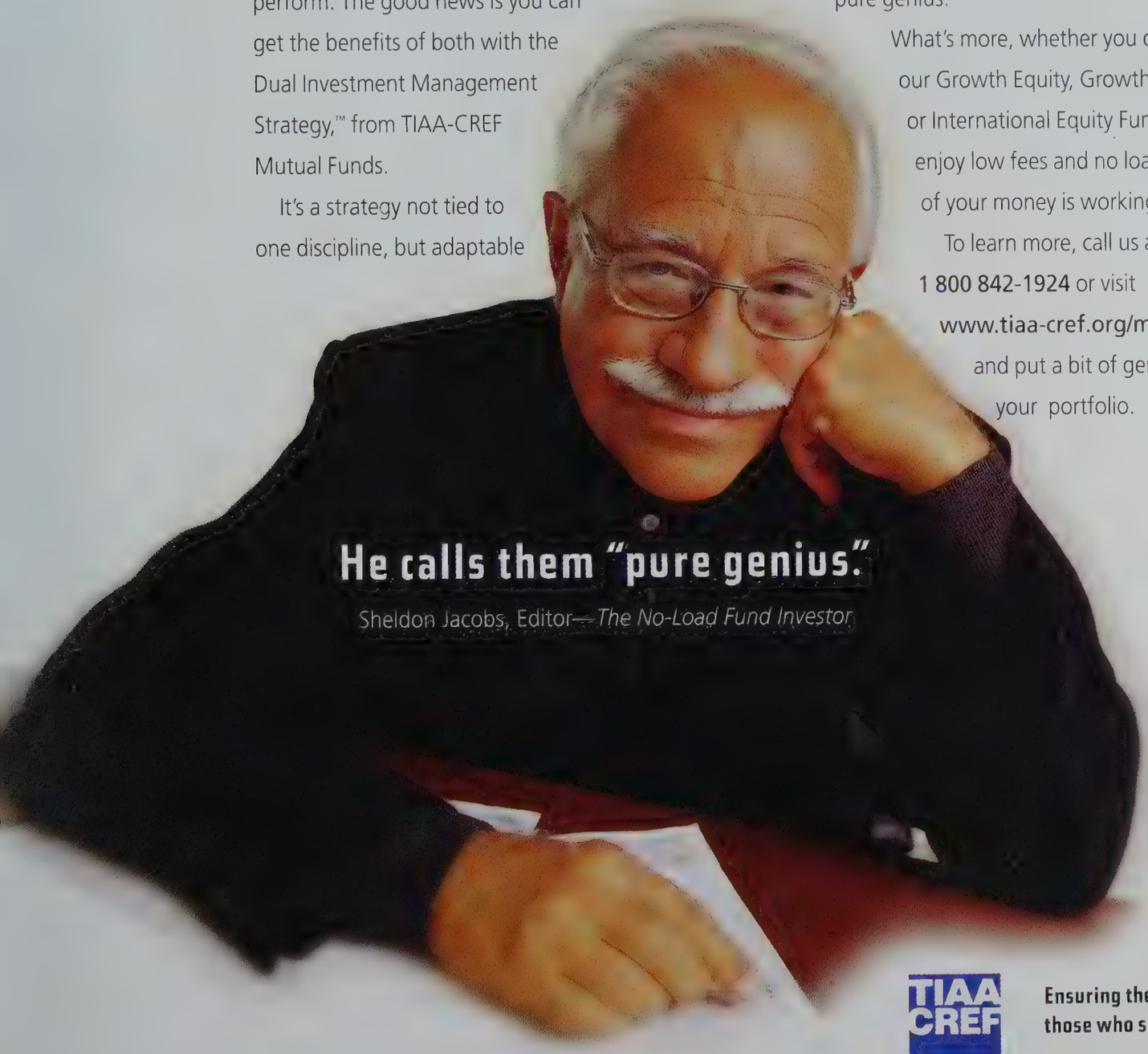

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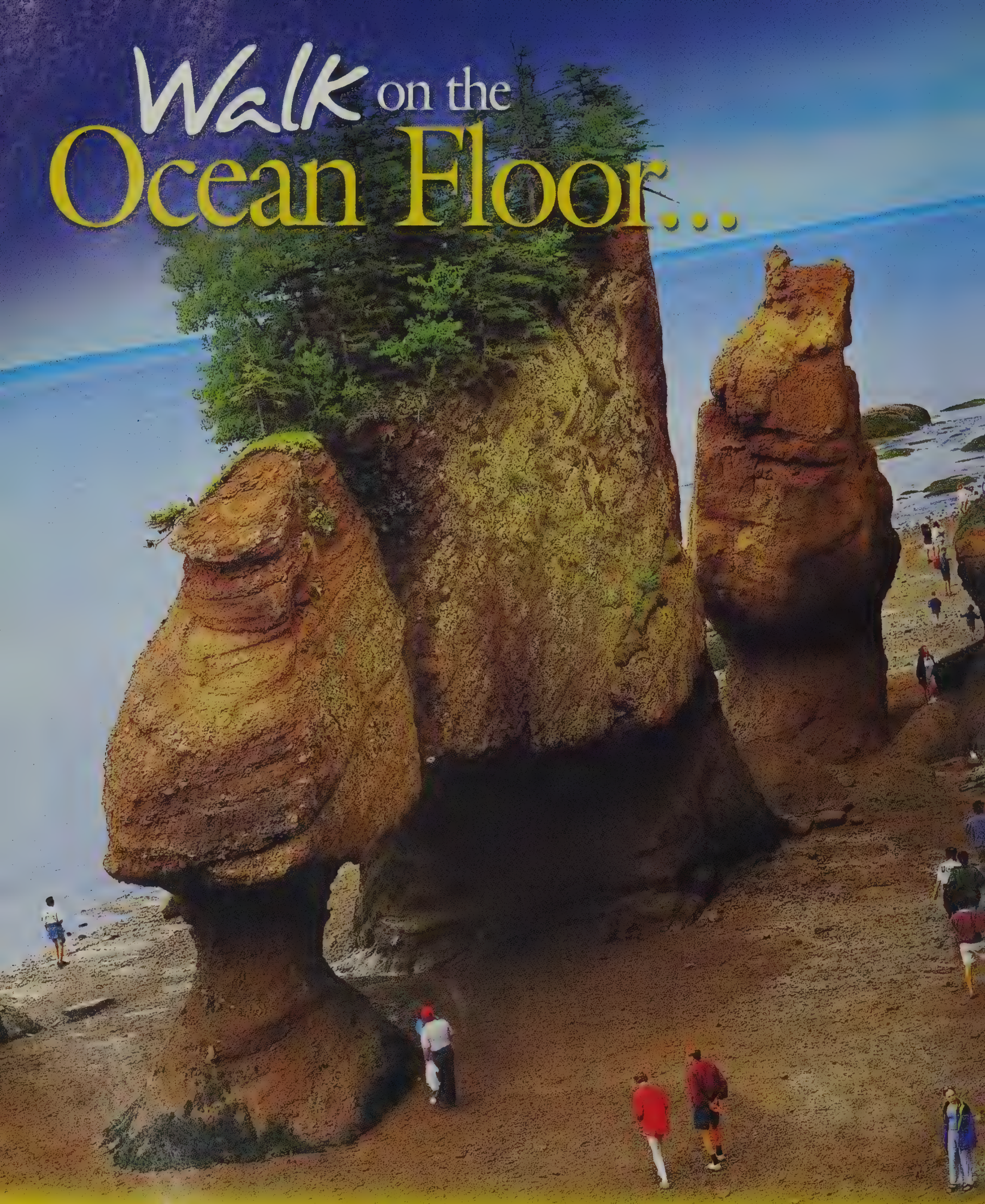

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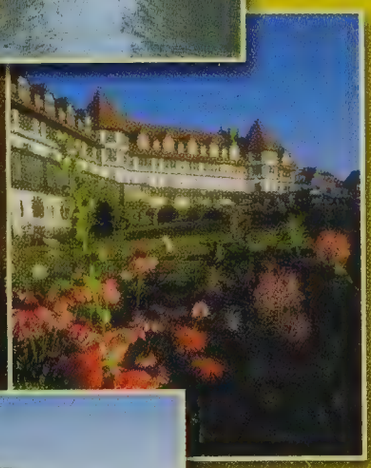

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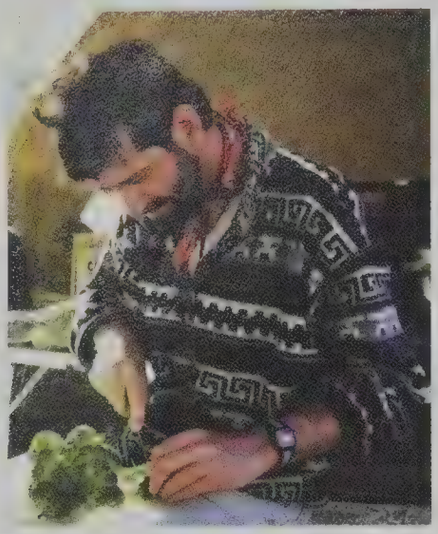
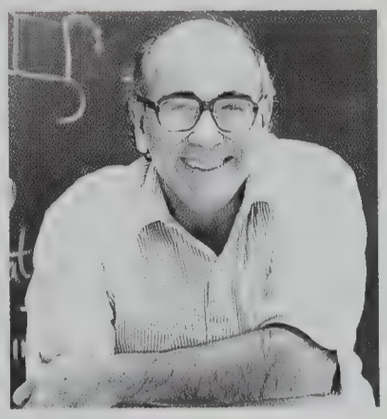


A curator in the department of paleobiology at the Smithsonian National Museum of Natural History, **Scott L. Wing** ("Hot Times in the Bighorn Basin," page 48) first went to the Bighorn Basin in 1972, the summer after he finished high school. By the end of that first field season, he was a confirmed desert rat—captivated by the solitude and beauty of the badlands, intrigued by the information that could be extracted from their rocks, and addicted to the intermittent success that fossil hunting brings. His research interests and love of the country have taken him back to this part of Wyoming nearly every year since then. Wing, left, has also chased plant fossils in other parts of the western United States and in deserts in Egypt, Cameroon, China, Argentina, and Pakistan. For more on Wyoming geology and history, he recommends John McPhee's *Rising From the Plains* (Farrar, Straus and Giroux, 1986). **Kenneth D. Rose** ("Wyoming's Garden of Eden," page 55) established a fossil museum in his basement when he was in high school, and on occasion he exhibited his collection publicly. His love of paleontology was strengthened by visits to the American Museum of Natural History and particularly by a trip to the Smithsonian, where several curators helped him identify fossil bones he had found in Florida. Now a professor of anatomy at the Johns Hopkins University School of Medicine in Baltimore, Rose has collected mammal fossils in Wyoming's Bighorn Basin for the past twenty years. He is also a veteran of fieldwork in other parts of the western United States, as well as in Egypt, Pakistan, and, most recently, the Indian state of Rajasthan. Rose's avocation, collecting marine fossils, dates from his basement-museum days and has led him to comb the coasts of North America, Africa, Japan, and the Philippines. The work of **Utako Kikutani,** who illustrated both Bighorn Basin stories, bridges the realms of art and science. Born in Japan, Kikutani spent her childhood in Kenya and Tanzania, where she became fascinated by and began to draw African wildlife. Ten years later, as she was about to complete a doctorate in zoology at the University of Tokyo, Kikutani read an article about the Guild of Natural Science Illustrators in the United States and realized that, for her, the "ideal work" would combine her interests in biology and drawing. A year later, she enrolled in the scientific illustration program at the University of California, Santa Cruz. Now a freelance illustrator in the New York City area, Kikutani contributes frequently to *Natural History* and enjoys "having opportunities to work closely with scientists and to visualize their world."

When the brothers **Anup** and **Manoj Shah** ("Tête-à-Tête," page 60) were children in Kenya, one of their favorite activities was visiting Nairobi National Park, where they spent long days watching lions, elephants, zebras, and other animals. They were educated in England, but their attachment to Africa and its animals never lessened; as adults, they returned to Kenya and became self-taught wildlife photographers, specializing in large mammals. The Shahs have also photographed in India and the rainforests of Indonesia. In the nine years since deciding to work as a team, they have taken four or five field trips a year. In the field, Anup (left, with Manoj) may shoot from a distance, using a long lens, while Manoj goes in for close-ups. Both brothers have received awards in the BG Wildlife Photographer of the Year contest and the Nature's Best and Cemex International Photography competition.

Born during World War II in the Sudetenland region of Czechoslovakia, **Walter R. Tschinkel** ("Colonies in Space," page 64) grew up in Texas, Alabama, and Connecticut. After attending Wesleyan University, he earned his doctorate in biochemistry at the University of California, Berkeley, with a thesis on chemical communication in beetles. He enjoys digging holes and can excavate a hundred cubic feet of earth in about an hour—an avocation that suits his passion for casting ants' nests in plaster. Tschinkel is currently the Menzel Professor of Biological Science at Florida State University, where for thirty years he has conducted research on how ants manage to function as a superorganism. He has published more than sixty scientific papers on the social biology of ants.



Originally trained as an astronomer, **Anthony F. Aveni** ("Other Stars Than Ours," page 66) was attracted to indigenous New World calendars thirty years ago, when he took a group of undergraduates to Mexico to see the Mesoamerican pyramids. An early result of that interest was his book *Skywatchers of Ancient Mexico* (University of Texas Press, 1980), which helped establish the field of archaeoastronomy—the study of the astronomical practices, celestial lore, and cosmologies of ancient cultures. A revised and updated edition of this classic will be published later this year. Among the other books Aveni has authored is *Between the Lines: The Mystery of the Giant Ground Drawings of Ancient Nasca, Peru* (University of Texas Press, 2000). Honored in 1982 as U.S. Professor of the Year by the Council for Advancement and Support of Education, Aveni is the Russell B. Colgate Professor of Astronomy and Anthropology at Colgate University in Hamilton, New York.

Ligia Botero ("Working Girl," page 74) began photographing life in the hills of Ecuador's Chimborazo Province in 1994. Shortly afterward, she took her first photographs of Rosa, the subject of her and Lynn A. Meisch's story. Botero, left, says she continues to document Chimborazo's "communal way of living" in an attempt "to show the fears and hopes of these indigenous peasants at a very decisive moment—when so many of them are uprooting and migrating." The Colombian-born photographer lives in New York City. **Lynn A. Meisch** has conducted fieldwork in Colombia, Ecuador, Peru, and Bolivia since 1973 and has published extensively on Andean life and culture. Meisch (far right, with Marta Conterón and son Alex) has twenty-four godchildren in Ecuador; they—not only her research—draw her back to the Andes each year. Deciding that education is wasted on the young, Meisch returned to school in her forties, receiving her Ph.D. in cultural anthropology from Stanford University in 1997. She is an associate professor of anthropology at Saint Mary's College of California in Moraga.

Having graduated from the University of Hawaii with a degree in biology, **Mike Severns** ("The Natural Moment," page 94) has spent his adult life as a diver, explorer, and marine photographer. With his wife, Pauline, he operates a dive boat operation in Hawaii that offers visitors tours of underwater wildlife, including the opportunity to observe the seasonal mass spawning of corals off the islet of Molokini. Severns, who dives to great depths using a U.S. Navy rebreather, has discovered the longest underwater cave system in Hawaii, an ancient Hawaiian fishing site, fossils of thirty extinct and previously unknown Hawaiian birds, and several new species of fish. His latest book, *Hawaiian Seashells*, a photo guide to 360 species of shells, has just been published by Island Heritage.

LETTERS

Analyzing Freud

In "Nature's Infinite Book" (2/01), Jared Diamond undertakes to compare and contrast the legacies of Darwin and Freud while missing a fundamental difference between the two. Darwin developed a scientific theory susceptible to test and to disproof. What Freud developed was closer to a system of religious belief than it was to a testable scientific theory.
Leonard Sax, M.D., Ph.D.
via e-mail

My problem with Jared Diamond's nomination of Sigmund Freud for membership in the august club of those who have made a "major, lasting difference to the course of science" is that Freud's work was not scientific. There is no objective way of confirming Freud's hypotheses or of disproving any of his concepts, since they are all based on interpretation.
Ronald G. Good
Louisiana State University
Baton Rouge, Louisiana

To find Jared Diamond placing Freud on a par with Darwin and publicly acknowledging the value of personal psychotherapy is refreshing and tremendously welcome. The theories of Freud, and of all depth psychologies, will continue to come in for assault simply because they focus on the unconscious, which remains largely unrecognized and uncharted territory. Freud was not dealing with the mind but with the psyche, of which mind is merely a part.
Meredith Sabini, Ph.D.
Berkeley, California

Darwin and Freud are both interesting and deserving scientists for Jared Diamond to ponder, but his concerns about pills versus talk therapy, in my experience and opinion, are wrong. From 1962 until 1983, talk therapy was used on my chronically depressed wife by psychologists, family counselors, several psychiatrists, a psychotherapist, and clergymen. After tens of thousands of dollars and years of tears, our family doctor began prescribing psychotherapeutic drugs. After four failed attempts, my wife is now enjoying a normal life.
Doug Swanson
North Branch, Minnesota

JARED DIAMOND REPLIES: I sympathize with Mrs. Swanson and with the many other people who were helped by psychotherapeutic drugs only after years of inappropriate talk therapy. However, I also sympathize with the growing number of people today who are inappropriately given drugs by clinicians lacking the patience, training, skill, or motivation to listen and to talk. As for the comments of Dr. Sax, Mr. Good, and other Freud-bashers, I say to them what I say to Darwin-bashers: There is substance to your critiques, but much more substance to Freud's and Darwin's achievements.

Alpha and Omega

On the matter of "last things" ("Universe," 2/01), readers and Neil de Grasse Tyson might enjoy a story attributed to Johannes Brahms and one of his friends. They were standing by the shore, and the friend was complaining that all the great music had already been written. "Look," said Brahms, pointing at the water, "here comes the last wave."
Roy Wagner
University of Virginia
Charlottesville, Virginia

Nisa Now

I read and enjoyed the book review in your 2/01 issue ("Long Live the !Kung"), but I have a question. As one of many anthropologists who has for years assigned the book *Nisa: The Life and Words of a !Kung Woman* in the courses I teach, I was under the impression that the cover photo was not that of Nisa, and I have discussed this point in the context of research ethics and protection of anonymity. However, that same photo appears in your review of the book's recent reprint with the caption "Nisa in 1971." Can you tell me if this is really the Nisa of the book?
Barrett P. Brenton, Ph.D.
St. John's University
Jamaica, New York

MARY KATE MACO OF HARVARD UNIVERSITY PRESS REPLIES: Indeed, *Natural History* wrongly captioned the photo on page 76. The late Marjorie Shostak, concerned with protecting the anonymity of her source, changed her subject's name to Nisa and did not publish a photograph of her in the original book. (A photograph of another woman was used, and this was what the magazine printed.) Shostak's sequel, *Return to Nisa,* was posthumously published. Harvard University Press, Shostak's husband (Mel Konner), and other anthropologists who knew the !Kung woman studied by Shostak decided to place a photo of the real "Nisa" on the cover and jacket flap of the second book. This decision was based on the knowledge that "Nisa" understood the success of the book and enjoyed knowing that her words would be published. The photo that appears in the *Natural History* review on page 77 is captioned correctly.

Erratum

In the 2/01 issue, we mistakenly identified the home institution of author Robert T. Mason ("Serpentine Cross-Dressers") as the University of Oregon. He is on the faculty of Oregon State University in Corvallis. We regret the error.

Natural History's e-mail address is nhmag@amnh.org.

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IN SUM

FATAL ATTRACTION Rats have evolved a strong, innate aversion to the smells of their predators. Healthy rats—even those bred for hundreds of generations in the laboratory—show distinct anxiety around feline odors. When the amoebic parasite *Toxoplasma gondii* gets into their brains, however, many of the rodents seem to lose their fear.

LARRY ANGIER

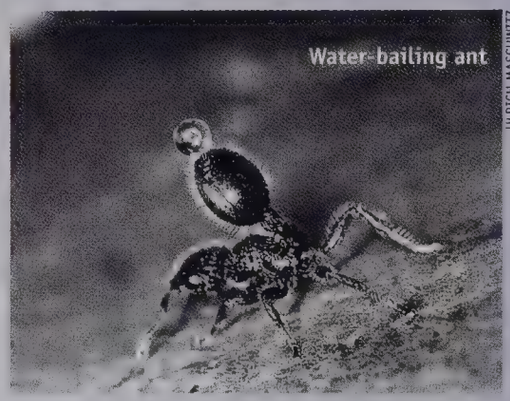
Close encounter

Zoologist Manuel Berdoy, epidemiologist Joanne Webster, and colleagues at the University of Oxford have studied the life cycle of *T. gondii* to test the hypothesis that the parasite manipulates the behavior of its intermediate host, the rat, to reach its ultimate target, the cat. The researchers infected captive rats with oocysts of the parasite and then placed them in large outdoor pens containing both cat and rabbit urine. Uninfected rats tended to shun the cat-scented areas, while the parasitized rats became substantially less afraid. With their fear of felines diminished, parasitized rats may become uninhibited about approaching their arch predators, with the predictable result of ending up as dinner.

Although all mammals are susceptible to infection by *T. gondii*, the amoebas can reproduce only within members of the cat family. Once *T. gondii* has bred in the brain of a cat that has ingested an infected rat, the parasite's oocysts are expelled with the cat's feces. After being washed away by rain, these oocysts can remain infectious in moist soil for more than a year. They can be ingested by beetles and worms, which are readily eaten by rats.

While the parasite affects rats' fear of cats, it appears to leave other aspects of rat behavior intact and to leave cat behavior completely unchanged. The Oxford researchers believe that *T. gondii* has evolved to alter rat behavior in this specific way and that the reduction of fear is not simply a side effect of cerebral malfunction. ("Fatal Attraction in Rats Infected With *Toxoplasma gondii*," *Proceedings of the Royal Society of London* B 267, 2000)

FLOOD RELIEF Ants that nest in underground colonies have developed various strategies to cope with flooding, including the formation of living rafts and the sealing of nest entrances. To deal with rain, arboreal ants often build their nests of waterproof leaves.


ULRICH MASCHWITZ

Water-bailing ant

But ants that nest in plant cavities, such as some of the eighty ant species that nest in and on Southeast Asian giant bamboos, have developed a unique strategy to bail out their colonies during heavy downpours.

Entomologists Ulrich Maschwitz and Joachim Moog, of Germany's Goethe-Universität, studied the reactions of the bamboo-nesting ant *Cataulacus muticus* to the flooding of its nest, both in a Malaysian rainforest and in the laboratory. These ants make their homes only inside the hollow segments of giant bamboo, where their colonies contain a queen, her brood, and as many as 2,000 workers.

When a nest became flooded, either by rain or artificially in the laboratory, the ants responded first by trying to keep the water out. Two or three workers blocked the nest entrances with their broad, flat heads. If that tactic proved ineffective, however, scores of workers came forward and drank as much water as they could. Each one then left the nest with a full abdomen and excreted water droplets on the outer surface of the bamboo's stem. According to the researchers, "This cooperative 'peeing' behavior is a new survival mechanism adaptive to the ants' nesting ecology." Experiments with two species of *Cataulacus* that do not live in hollow bamboo revealed no forms of water-bailing behavior. ("Communal Peeing: A New Mode of Flood Control in Ants," *Naturwissenschaften* 87, 2000)

CRABS: A LANDMARK STUDY Some crabs find their way back home the same way people do—by observing and memorizing landmarks. Biologist Stefano Cannicci, of the Department of Animal Biology and Genetics at the Università degli Studi di Firenze, and colleagues studied the homing behavior of *Thalamita crenata*, a crab found in large numbers on an intertidal mudflat north of Mombasa, Kenya. In one set of trials, the researchers left variously colored concrete bricks and tiles around the animals' underwater dens for a few days, until they became accustomed to the objects. The artificial landmarks were then repositioned in the same configuration some distance away, and the crabs were displaced from their dens. Continuing to use the old landmarks, the crustaceans aimed for a "false home," directed by the misleading information they were given. The researchers concluded that the crabs showed good spatial knowledge and cognitive memory, resulting in a much more flexible ori-

STEFANO CANNICCI

Observant crab

enting mechanism than those of other crabs—"comparable to the route-based memory of honeybees." ("Homing in the Swimming Crab *Thalamita crenata*: A Mechanism Based on Underwater Landmark Memory," *Animal Behavior* 60, 2000)—*Richard Milner*

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Throughout the state, enclaves of natural wonder prove [illegible] some of the most beautiful wilderness [illegible] West Virginia has been [illegible] in preserving its [illegible] so visitors can discover this naturally wild and wonderful state.

For vacationers who are naturalists at heart, stop by the Cranberry Glades nestled in a remote valley within the mountains of Pocahontas County. It is unusual to find cranberry bogs in the southern United States, but West Virginia, with the highest mean altitude of any state east of the Mississippi River, has four bogs that cover more than 600 acres.

Cranberry Botanical Area, within Cranberry Glades, has a number of plants that many people wouldn't expect to find in this region of the country, including the serviceberry, bog rosemary, and two varieties of cranberries that give the wilderness its name. In addition, Cranberry Glades is home to white-tailed deer, beaver, and black bear, as well as ruffed grouse and great blue herons.

Two of the bogs are open to the public and a large boardwalk allows visitors to view these pristine areas without disturbing them. The rest of Cranberry Botanical Area is reserved for scientific and educational programs.

Farther south, vacationers can take advantage of the New River Gorge area, a smaller version of the Grand Canyon that cuts a path through the mountains, nourishing the woodlands and offering both a recreational and vast conservation area. With more than 63,000 acres, the New River Gorge area is an outdoor lover's paradise. Visitors can take a whitewater rafting trip, hike [illegible] of the many trails, horse back ride, fish, and even take a llama trek.

[illegible] Tamarack, with its crown [illegible] is the [illegible] state collection of [illegible] in the country. For a hand-made nineteenth century pattern quilt, or a piece of heirloom glass, Tamarack is the place to go. Visit this state treasure to sample some native West Virginian cuisine, music and entertainment.

One of the arts most associated with West Virginia is glassmaking. There are no fewer than ten glass factories and stained glass creators in the state. Among them is Fenton Art Glass, located along the Ohio River in Williamstown, just north of Parkersburg. Started in 1905, the family-owned and operated Fenton Art Glass produces its wares the old-fashioned way, and visitors are invited to watch the process during daily tours.

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This special editorial/advertising supplement was created by the Natural History Special Sections Department and did not involve the magazine's editorial staff. • **WRITER:** *Stephanie Fekety* • *DESIGN: Mindy Phelps Stanton*
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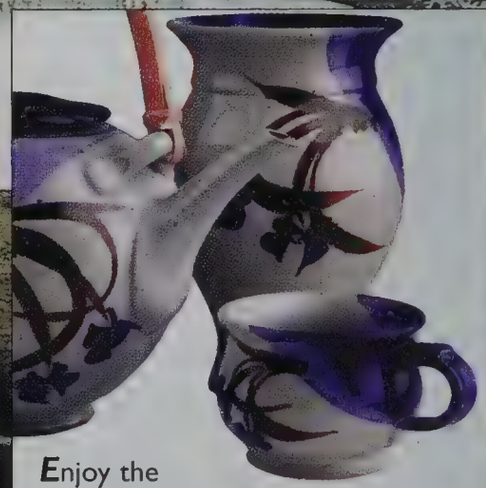

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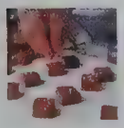

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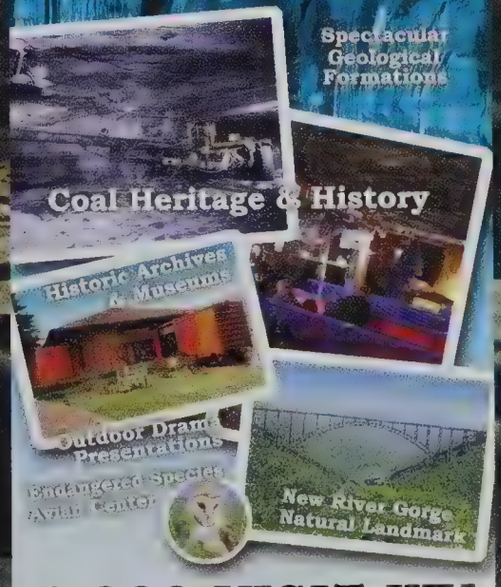

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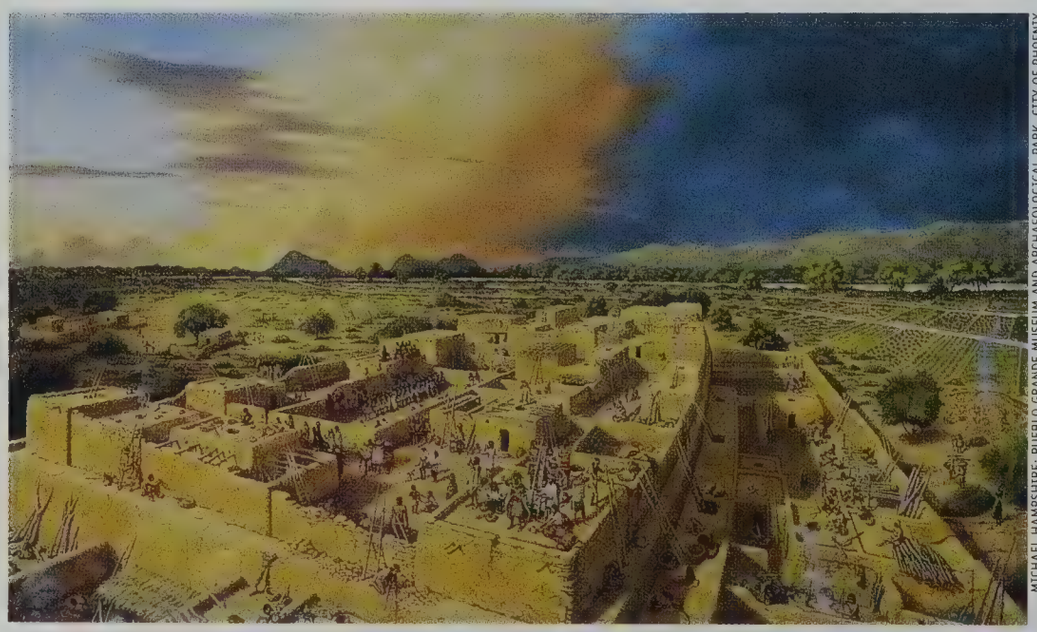

MICHAEL HAMPSHIRE; PUEBLO GRANDE MUSEUM AND ARCHAEOLOGICAL PARK, CITY OF PHOENIX

Artist's conception of the Pueblo Grande mound in prehistoric times

The Rise of Phoenix

The capital of Arizona owes its birth to the handiwork of the ancient Hohokam.

By Samuel M. Wilson

In 1868, when the name "Phoenix" was chosen for what would become the capital city of Arizona, the reference to a creature reborn from its own ashes was not entirely a romantic notion. The Anglo- and Mexican Americans who began to settle the Phoenix basin in the mid-nineteenth century found the ruins of towns built by the Hohokam ("the people who have gone," as they were dubbed by later indigenous people). The Hohokam lived in this northern part of the Sonoran Desert from the last few centuries B.C. until A.D. 1450; toward the end of that period, as many as 80,000 people may have populated the basin. To feed their population, the Hohokam grew corn and other crops, which they irrigated with water from the Salt River by means of about 500 miles of canals. To a great extent, the modern city owes its very existence to those abandoned canals.

The city's rebirth began in 1867, when Jack Swilling, who had been employed variously as a Confederate soldier, a Union Army scout, and a miner, passed through the area and met John Y. T. Smith, one of the first settlers. Smith told him of "diggings" he thought might be mines, inland from the river, but on inspecting these channels Swilling quickly understood their real purpose:

> *By the end of my third afternoon there I was convinced that I had examined nothing less than an extensive system of canals and ditches whose function had once been to bring the water of the river to the farms of a country with rich soil but no rainfall to speak of.*

Jack Swilling began a new career as founder of the Swilling Irrigating and Canal Company, which cleaned out a few of the abandoned canals. "As long as we're following their lead," Swilling wrote, "we ought to walk in the same tracks." Soon the canals were watering a growing settlement, just as they had served Hohokam towns centuries before.

Like the core of modern Rome or Mexico City, central Phoenix has archaeological remains almost everywhere you look—and they turn up whenever a sewer line is dug, a foundation is excavated, or a road is built. More than 300 sites are known just within the city limits. One of them, La Ciudad ("the city," in Spanish), was once home to several hundred people. It included a platform mound—a rectangular construction of stone walls filled with dirt, often the result of periodic expansion and remodeling. This one was 150 feet long, 110 feet wide, and nearly 50 feet high. On and around it the Hohokam would have constructed houses of mud, stone, and cementlike caliche. La Ciudad is one of several similar large sites spread around the irrigated basin.

The large platform mound of La Ciudad has practically vanished following 150 years of urban development. (One early-twentieth-century landowner even charged daily admission to anyone wishing to dig up artifacts from the site.) But it's hard to erase some 30,000 cubic yards of material. Armed with a modern map and a map from 1868, photographer

David Ortiz and I spent a morning surveying some of the empty lots scattered through downtown Phoenix, and eventually we were able to identify a remnant of La Ciudad. It is now only about ten feet high and paved over by the parking lot of St. Luke's Medical Center at the corner of 18th and Van Buren Streets. No traces seem to remain of the canals that were once located near it.

We also poked around an undeveloped city lot, a leftover triangle enclosed by train tracks, a large concrete-lined irrigation canal, and huge highways. We saw evidence that in historic times this land was used for farming, grazing, and as a dump

PHOTOGRAPHS COURTESY OF PUEBLO GRANDE MUSEUM AND ARCHAEOLOGICAL PARK, CITY OF PHOENIX

for stockyard manure. Piles of dirty blankets and old shirts showed that it now serves as a camping spot for the homeless. There were signs of the vanished Hohokam as well. Small, reddish brown pot shards dotted the ground, interspersed with worn-out or broken remains of stone hoes. And two ridges of earth that more or less paralleled the nearby bed of the Salt River—which in this spot is almost entirely dry—proved to be remnants of an eighty-foot-wide canal, large enough to have carried a fair portion of the river's water. It was once one of the main canals, extending more than ten miles to serve the agricultural plots of Hohokam villages.

Visitors to Phoenix who are reluctant to venture into empty lots can turn instead to the Pueblo Grande Museum and Archaeological Park, located north of the Salt River and east of the city's airport. The centerpiece is a rectangular platform mound as big as a football field and twenty to thirty feet high. Its construction was begun about A.D. 1150, with further expansion during the next 300 years. Hohokam houses were once scattered up to half a mile around the mound; the society's elite were housed on its top, where they probably had rooms designed for

A bird motif decorates a Hohokam pottery shard, above. A fragment of a shell bracelet, above left, with a carving of a frog.

determining solstices and carrying out other rituals. The site may well have boasted one or more multistoried buildings akin to the Hohokam big house (*casa grande,* in Spanish) that may be seen at Casa Grande Ruins National Monument, fifty miles southeast of Phoenix.

North of the platform mound is one of the site's ball courts, now excavated and restored. A depression about forty feet wide by eighty feet long, the court was most likely used by teams who competed in a Southwestern version of the ball game played by many indigenous groups in the Americas and the Caribbean. Participants had to keep a ball in play without touching it with their hands or feet. Wherever this game was played, it was intertwined with religious ritual, intervillage rivalry and cooperation, trade, and good fun.

In addition to a paved trail that guides visitors to the top of the platform mound and around it to the ball field, the Pueblo Grande Museum maintains archaeological exhibits, interactive multimedia displays, and interpretive exhibits on the prehistory of the Southwest. The museum also houses the office of the city archaeologist—an unusual position in the United States but one that this city really needs. In fact, Phoenix had the first city archaeologist in the nation:

Odd Halseth, hired in 1929, who on a shoestring budget built the first museum at Pueblo Grande, using adobe, scrounged materials, and convict labor.

Today the position is filled by Todd Bostwick, who has written extensively about Pueblo Grande and the Hohokam canals. Bostwick often finds himself caught between the demands of Phoenix's explosive growth and the need to preserve and protect some of North America's most extraordinary heritage. It's a job that calls for political skill and the ability to make difficult choices, because the laws concerning archaeological remains are a rather porous combination of federal, state, and local measures. One of Bostwick's immediate goals is to save the last of the big canals—the ones in the triangular lot we inspected—and turn them into a public park.

South of the Salt River and a little way upstream, in the adjoining city of Mesa, the Park of the Canals offers a snapshot of three periods of canal use. Surrounded by suburban plots of irrigated greenery, the thirty-acre park looks at first like a forlorn patch of the Sonoran Desert. Creosote bushes grow head-high and lizards walk by on tiptoe, keeping their bellies off the scalding dirt and gravel. A closer look reveals shallow channels bordered by linear ridges. There is a Hohokam canal, somewhat eroded but still quite visible in the bare landscape. Branching off from it is one built by Mormon colonists in the late 1800s. It, in turn, is cut by a modern, concrete-lined canal that carries a stream of water. Why successive canal-builders chose to take slightly different routes is unclear, but pehaps irrigation eventually resulted in the salinization of tracts of farmland. The Salt River was given its name for good reason.

Samuel M. Wilson, an associate professor of anthropology at the University of Texas at Austin, is the author of The Emperor's Giraffe and Other Stories of Cultures in Contact *(Westview Press, 1999).*

DAVID ORTIZ

JOE LEMONNIER

Left: A parking lot sits atop remnants of the platform mound known as La Ciudad. Below left: A Hohokam irrigation canal in Mesa's Park of the Canals.

DAVID ORTIZ

For visitor information, contact:

Pueblo Grande Museum and
Archaeological Park
4619 East Washington Street
Phoenix AZ 85034
(602) 495-0901
www.ci.phoenix.az.us/PARKS
/pueblo.html

Park of the Canals
Mesa Convention and Visitors Bureau
120 North Center Street
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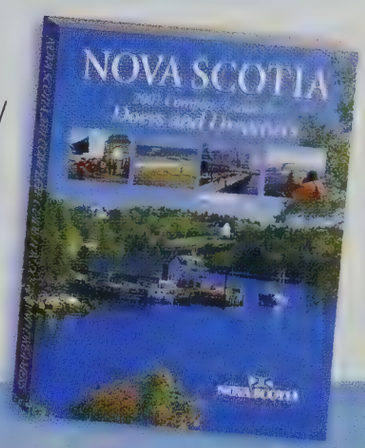

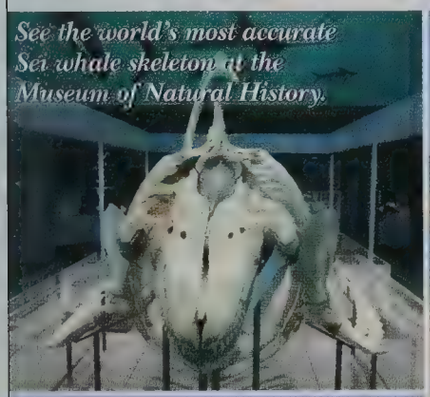

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NOVA SCOTIA
CANADA'S SEACOAST

IN THE FIELD

Found Object

By Bernd Heinrich

Beautiful winged things come in small packages.

The snow on the steep, south-facing slope of Raven Ridge, near my house in Vermont, was melting quickly in the April sun. I was scrambling up toward the ravens' cliff nest to check on its progress. Climbing the hill up to the base of the cliff is a treat, because here is where I always find the first bare patches of ground after seeing only deep snow for almost six months. The sun reaching this slope cuts through the snow early, revealing a moist layer of fallen oak, maple, and ash leaves. On this day, the first hepatica buds were poking through the leaf mat, and some were opening into startlingly light-blue flowers.

As I searched for a secure footing on some protruding rock, a roundish object caught my eye. It was about the size and shape of a shelled hickory nut but had bits of dead maple leaf adhering to it, as though it had once been wrapped in a leaf that had then withered and partially peeled off. I had on rare occasions found such an object before, and I recognized this one. It was the cocoon of a Saturniidae silk moth, possibly a luna or a polyphemus moth. As adults, both of these moths are stunning aerial creatures, but I had seen them only after raising them from caterpillars and after attracting them to a light at night, when they are active.

Silk moth cocoons are made of a layer of silk that the caterpillar exudes from glands in its mouth. While the silk of Saturniidae moths is considered inferior to that of Asian silk moths, it is tough and durable. The caterpillar, or larva, lays down the silk in one continuous strand, endlessly weaving its head back and forth and frequently changing position. The strands glue themselves together into a resilient fabric that I cannot tear apart with my fingers. Once enshrouded in silk, the larva enters a new stage, that of the pupa. The energy stored in the pupa itself will last the insect the rest of its life: eight months of pupation and a few days of adulthood. (Adult moths have neither feeding mouthparts nor digestive tracts.) While rodents often succeed in opening cocoons and extracting the nutritious pupae, birds rarely invest the time and effort needed to pierce the silken armor. The moth itself can escape from the cocoon only by secreting an enzyme that dissolves some of the silk and creates an exit hole.

This cocoon had no exit. I shook it slightly and from its heft and rattle I knew that it contained a live pupa. I put it in my pocket and continued on to the ravens' nest, thinking that good things often come to one obliquely.

After coming home, I placed my find in a screened cage, which I left outside, on the back porch. The pupa had long been in a state of torpor, but shortly after receiving signals of warmth in spring, its biological clock would restart and its development toward adulthood would resume. If I had taken the cocoon into the house, the premature warmth would have disturbed the insect's timing. If a moth is to find a mate, as well as fresh leaves on which to deposit its eggs (if it is female), then it must emerge and live out its few adult days at the same time as the rest of its population. Up to now the insect's life had progressed at a leisurely pace; indeed, most of it had been spent in torpor. After emerging, though, life would take on urgency.

My moth emerged on the bright sunny afternoon of May 30. I saw it hanging from the ceiling of its cage; it cannot have been out for more than an hour. Its limp, still-soft wings of cream and various browns, with touches of pink, were folded over its thorax and abdomen, which were covered with a light down. This thin cloak acts as insulation when the moth begins to shiver and warm up in preparation for flight. This was a polyphemus moth (named for the Cyclops of Greek mythology); each hind wing bore a large blue-black "eye."

DWIGHT KUHN
Leaf-shrouded cocoon

The mission of this moth would be to lay eggs. It was a female, as evidenced by its plump, rounded abdomen and thin antennae. Males have broad, feathery antennae that provide ample space for millions of chemical sensors tuned to detect one kind of molecule: the scent of a female of its species. This fine-tuning of the senses provides the moth with a very narrow window on the world, but it is both sufficient and efficient.

DWIGHT KUHN
A polyphemus caterpillar

After the moth had dissolved her way out of the tough cocoon, she must have quickly crawled to where she could dangle her wings, pumping

E.R. DEGGINGER; COLOR-PIC, INC.

A female polyphemus moth and newly laid eggs

blood into them and expanding them to their full length of almost three inches. Over several hours, a hormone released into her blood would serve to harden her wings and the rest of her exoskeleton. Then she would be flight-ready.

I tied a thread around the moth's waist and then attached her loosely to a low branch of the oak tree next to my house. Oak is one of several food plants used by polyphemus caterpillars. As soon as I released my grip on her wings, she shivered, isometrically contracting her wing muscles to increase her thoracic temperature to about 97° F, sufficient for takeoff. Attempting to fly, she fluttered for three or four minutes before folding her wings over her back and coming to rest, pendent under a leaf.

The next dawn I eagerly checked on her. Not only was she still attached to the twig by the thread but she was also attached to a male. Literally. Belly to belly, with the tips of their abdomens joined, the motionless couple looked like dead leaves. This was a useful camouflage, as they were both cool, torpid, and temporarily unable to fly after their probably nightlong tryst. At midmorning the male disengaged, and after vibrating his wings for a minute or two to warm up, he flew off. He, possibly, would mate again. She would not. But neither had any time to lose.

By noon, the female had laid seven eggs, her total for the first day. Each egg was about the size of a peppercorn, somewhat flattened, and brown around the circumference. Yellow in the middle when first laid, the eggs quickly turned white. To me, the most amazing thing about the eggs was their adhesive property. The moth laid each one separately. She extended her otherwise round abdomen, acrobatically bending it into a C-shape, probed a leaf surface with its tip, and extruded an egg that instantly stuck fast, thanks to its coating of quick-drying, nontoxic superglue. The female's second night was devoted to egg laying; she deposited more than thirty eggs on the leaves and twigs around her. The following day and night, she laid just a few more. Had she not been tethered, the moth would have avoided laying all her eggs in one place. Flying to several sites to deposit eggs is a strategy used by all moths and butterflies whose caterpillars must hide from predators. Only adults whose caterpillars are noxious to birds lay their eggs in a single mass.

After three days the moth was spent, and dead. Most of her colorful scales had worn off; she was bald. I looked forward to seeing the eggs hatch in a few days' time and to watching the caterpillars grow on my oak tree throughout the summer. A luminescent, almost translucent green with red dots and small silver highlights, they blend artfully into the foliage and are almost invisible, despite being relatively large—about the size of my thumb. I would eventually watch some of them don a mantle of leaves and begin the process of weaving their own silk cocoons.

As to the spent female, I examined her slimmed-down abdomen and found four more eggs, partly developed. She had succeeded in laying nearly a full clutch. As an adult she had not lived long, but I granted her immortality by recycling her into a young raven.

Bernd Heinrich is a professor of biology at the University of Vermont, Burlington.

BIOMECHANICS

Prepared for the Past

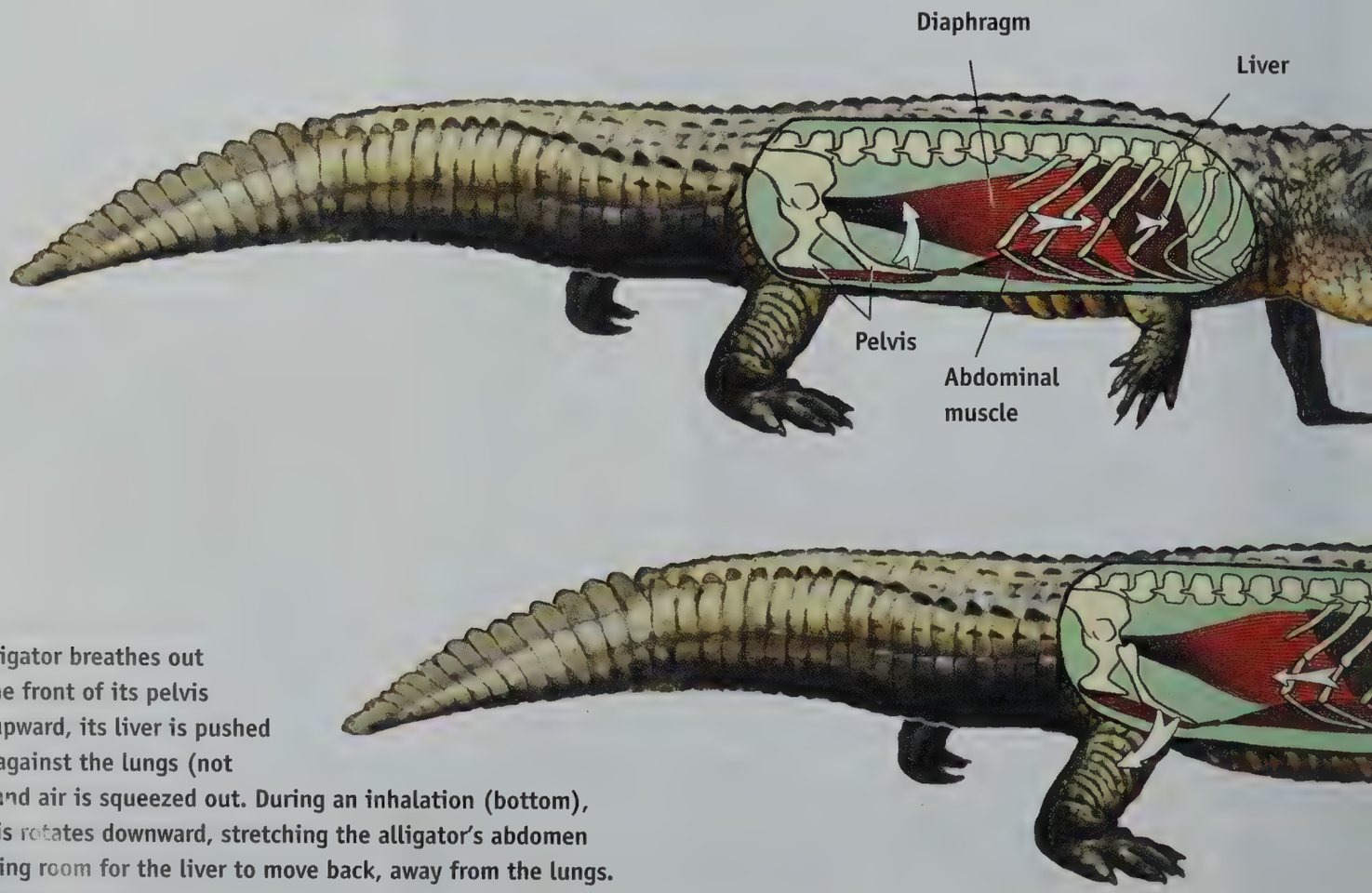
Thanks to their landlubber ancestors, alligators have more breathing power than they need.

Story by Carl Zimmer ~ Illustrated by Sally J. Bensusen

Most of the time, evolution hands out its gifts sparingly. Natural selection generally produces animals that are well designed for the lives they lead—but not *too* well designed. Some hawks have eyes sharp enough to see a mouse up to 300 feet away, but not 1,000 miles away. After all, everything in life has a cost. An owl with eyes the size of beach balls might be able to see quite far, but it would have a hard time flying (let alone pumping enough blood to its eyes to keep them working properly). Some animals, however, do seem to be overdesigned. One of these is the American alligator *(Alligator mississippiensis)*.

Recently, biologists Colleen Farmer and David Carrier, of the University of Utah, measured the breathing patterns of alligators. When an alligator is resting, it breathes intermittently, taking one breath per minute, much like other cold-blooded reptiles. To study alligators on the move, Farmer and Carrier trained them to do four-minute bouts on a treadmill. The scientists placed a mask over each alligator's nose to measure how much air the animals inhaled and exhaled.

Your typical reptile—an iguana, for instance—can't take deep breaths while walking. To exhale, an iguana uses some of its trunk muscles to squeeze its ribs, compressing the lungs and forcing



As an alligator breathes out (top), the front of its pelvis rotates upward, its liver is pushed forward against the lungs (not shown) and air is squeezed out. During an inhalation (bottom), the pelvis rotates downward, stretching the alligator's abdomen and making room for the liver to move back, away from the lungs.

out the air. As long as the animal is resting, this presents no problem. But when walking, it must use these same muscles to bend from side to side. The demands of walking and breathing thus come into conflict. Making matters worse, a walking iguana needs more oxygen than a motionless one. For iguanas and many other reptiles, the solution is to take quick, shallow breaths when they walk and never to walk very fast. (Some lizards can sprint, but they can't keep it up for more than a few minutes.) Modern lizard skeletons look a lot like the oldest reptile fossils, suggesting that reptiles are still constrained the same way they were some 300 million years ago.

But not alligators, as Farmer and Carrier discovered. As soon as these animals started moving on the treadmill, they began to breathe deeply at regular intervals (about thirteen times per minute). Their walking breaths were four times deeper than their resting breaths—in fact, relative to their weight, alligators take in more air per breath than has been reported for any other exercising animal.

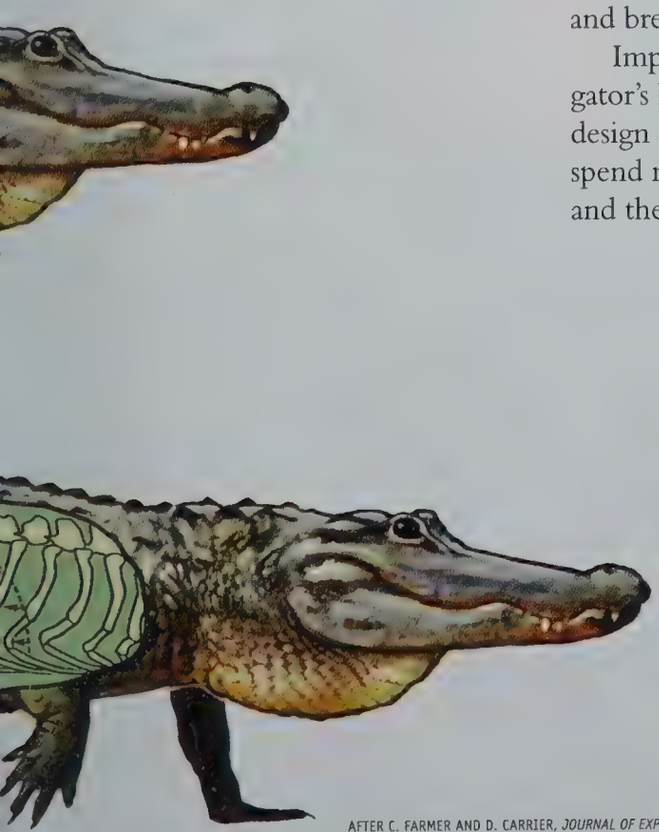
Alligators manage such an unreptilian feat because they don't rely solely on rib muscles to breathe. When an exercising alligator exhales, its liver is pushed forward, ramming against its lungs and squeezing the air out. During an inhalation, a muscle attached to the pelvis pulls the liver back, creating negative pressure that draws air into the lungs.

Farmer and Carrier have discovered that the alligator's liver-pump system is even more sophisticated than previously thought. Every time the animal breathes in, muscles rotate the front of its pelvis downward. This hip rotation stretches the abdomen, making room for the liver and for the muscles that retract it. When the alligator exhales, the front of the pelvis rotates back up and the abdomen shrinks, forcing the liver forward again. None of the muscles that help move the liver are involved in bending an alligator's trunk from side to side, so there is no conflict between walking and breathing.

Impressive, yes, but given the gator's lifestyle, this biomechanical design seems over the top. Alligators spend most of their time lying around, and their hunting style involves lurking in the water, motionless, and then suddenly ambushing their prey. A lion or a wolf may sometimes need to breathe deeply for long periods while running after prey, but putting a liver pump in an alligator is a bit like hooking a jet engine to a hang glider.

To explain this apparent excess, Farmer and Carrier point out that today's alligators and crocodiles look very different from their ancestors. Those early reptiles, known as crocodylomorphs, date back about 240 million years and were the size and shape of a coyote with a heavy tail. They had long slender legs that fit under the body rather than sprawling out to the sides, and they ran on the balls of their feet. Farmer and Carrier speculate that the ancestors of crocodylomorphs evolved special breathing mechanisms for sustained locomotion on land—a liver pump complete with rotating hips, which would have allowed them to take the deep breaths needed to gallop. And indeed, the pelvis bones of fossil crocodylomorphs show features that could have played a role in driving air in and out of an animal's lungs.

Perhaps 100 million years after the first crocodylomorphs trotted across the land, their descendants shifted to an amphibious way of life. Their legs grew short, and their tails became stout—an adaptation for swimming. Yet they retained the powerful hip-driven system for breathing. Whatever the reason, today's alligators are biomechanically prepared for a way of life that vanished 140 million years ago.



AFTER C. FARMER AND D. CARRIER, *JOURNAL OF EXPERIMENTAL BIOLOGY* 203:11, 2000

Carl Zimmer's new column, "The Evolutionary Front," debuted in March and will appear bimonthly. Starting in June, "Biomechanics" will be written by Adam Summers, assistant professor of ecology and evolution at the University of California, Irvine.

NATURE'S INFINITE BOOK

Deaths of Languages

Six thousand languages are spoken today. By the end of the century, we may be down to two hundred.

By Jared Diamond

YVONNE BUCHANAN

In this magazine, the phrase "tragic loss of diversity" usually refers to the current disappearance of biodiversity, with its big, though indirect, consequences for humans. However, another tragic loss of diversity has been going on for a long time, and it has more direct consequences for us: the extinction of our languages.

Language is the most complex and distinctive product of the human mind. Possession of language is the most important trait distinguishing us from apes, and differences among languages constitute the most important distinctions among human groups. In addition to being the focus of each group's culture and the vehicle of its literature and songs, a language provides detailed clues to a people's history, just as do their bones, genes, and faces. Unfortunately, thousands of languages disappeared in recent millennia as their speakers were conquered or exterminated by dominant groups or assimilated into them. Farmers have overwhelmed hunter-gatherers, and strong states have overwhelmed weaker states and tribes. Whatever the original number of languages spoken in the world at the end of the Ice Age (I'd guess tens of thousands), we are down to about 6,000 today.

Most of those 6,000 languages are actually moribund, now spoken only by older people and being learned by few, if any, children. Moribund languages are being eliminated not so much through murder of their speakers (as in the past) as by a more insidious process: the use of a few dominant national languages in governments, schools, businesses, movies, videos, and on the Internet. At this rate, by the end of this century we shall have lost 97 percent of our remaining languages, and barely 200 will survive. That would be a gigantic intellectual and cultural loss for all of us.

This article is about the Ostrogothic and Frisian languages, two members of the Germanic language group—to which English, too, belongs. Ostrogothic disappeared about two centuries ago. Nothing is known of it except for

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a list of 101 words obtained from one of its last speakers. With the extinction of the Ostrogothic language, the longest-surviving Gothic people finally disappeared from history. The other language, Frisian—the modern language closest to English—still hangs on as a minority language in the Netherlands, backed at the eleventh hour by the resources of the majority Dutch-speaking government and by the pride of the Frisian people. The story of Ostrogothic exemplifies what we have already lost; the story of Frisian exemplifies what we can still save.

Today, Germanic languages and peoples fall into two groups: North Germanic, alias Scandinavian (Swedish, Danish, Norwegian, Icelandic, and Faeroese), and West Germanic (German, English, and Frisian). Around the time of Christ, though, many East Germanic peoples lived on the coast of the Baltic Sea in what are now eastern Germany and Poland. These groups are collectively termed the Goths (and individually known as the Visigoths, Ostrogoths, Burgundians, and Vandals) and were prominent among the so-called barbarians who destroyed the Western Roman Empire. Early in the Christian era, the Goths migrated south to establish kingdoms in North Africa and much of Europe, such as the Ostrogothic kingdom in the Ukraine. But all of those Gothic kingdoms eventually succumbed in battle to assorted other peoples, the last to fall being Spain's Visigothic kingdom, conquered by Arabs in A.D. 711.

All that remains of Ostrogothic is contained in a list of 101 words obtained from one of its last speakers.

For most Gothic languages, our only information consists of a few words quoted by Roman authors. Our sole extensive Gothic text is a partially preserved translation of the Bible into Visigothic, made circa A.D. 340 by Bishop Wulfila, inventor of the twenty-seven-letter Gothic alphabet. The translation is doubly significant as the earliest extensive text preserved in any Germanic language. However, from the ninth century onward, travelers to the Crimean Peninsula (which projects from southern Ukraine into the Black Sea) reported encountering there, among other groups, people who had distinctive customs and spoke some obviously Germanic language. As time went on, such reports began mentioning that these people were becoming multilingual, using their own language less, and adopting the Islamic faith and Turkish dress. The last report of a Crimean Germanic language, in 1780, came from a visitor who described meeting some Turkish-looking people speaking a Germanic language among themselves without knowing that it was Germanic. Their assimilation appeared to be complete by 1794, when another visitor to the Crimea reported that he could find no trace of such a language.

What made these reports so intriguing was that the Crimea had once been part of the Ostrogothic kingdom. Could those Crimeans really have been the last Goths, continuing to speak Ostrogothic for more than a thousand years after their kingdom fell? Or were they relatively recent immigrants from the area of modern Germany? That is, was their language some type of German, or was it something more like the Visigothic of Wulfila's translated Bible? Alas, almost all those visitors to the Crimea failed to write down even a single word of the mysterious language they heard. The one exception was a Flemish diplomat and man of letters named Ogier Ghislain de Busbecq, who served as the Austrian ambassador to Istanbul from 1555 to 1562. Busbecq was very curious about whether those Crimeans were indeed the last Goths, and he begged his interpreters to be on the lookout for any who might be visiting Istanbul. Finally, two of the Crimeans showed up in Istanbul, and Busbecq's interpreters brought them to dinner. A highly educated man and an accomplished linguist familiar with at least nine languages, Busbecq quizzed them in detail for several hours, got them to pronounce 101 words, and carefully recorded the meanings of those words as explained through his interpreters. A letter describing the dinner, sent by Busbecq to a friend, contains everything we know of that vanished Crimean language.

Linguists nearly weep in frustration at the sequence of steps by which those words have come down to us. To begin with, Busbecq wrote that of his two visitors, one really was a "Goth" (Busbecq's term, which I shall adopt) who had completely forgotten his own language because it was already falling into disuse. The real informant was the other guest, not a Goth at all but a Greek who had learned Crimean "Gothic" (Busbecq's term again) while living in the Crimea and who presumably pronounced it with a Greek accent. Busbecq's interview procedure was evidently to have the Greek visitor carefully pronounce a Gothic word and then explain its meaning in Greek, which Busbecq understood only imperfectly—so his Greek interpreter translated the explanation into Italian, in which Busbecq was fluent. Busbecq then translated the Italian into Latin, the language in which he wrote the letter to his friend. Because the phonetic alphabet now used by professional linguists hadn't yet been invented, Busbecq used either German or Dutch spellings to transcribe the Greek visitor's pronunciation of the Gothic words, depending on how the word sounded to him. Ultimately, a copy of

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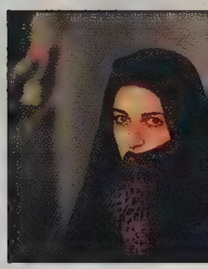

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Busbecq's handwritten letter in Latin fell into the hands of a French printer, who had difficulty reading Busbecq's handwriting but who published the letter anyway, without Busbecq's permission. The printer knew neither German nor Dutch and probably overlooked some typesetting mistakes.

Errors must have crept in at each stage of this process. Confronted with such complications, some linguists have thrown up their hands and despaired of reaching any conclusions about Crimean Gothic. But dozens of others have been struggling for more than four centuries to peel off the errors at each stage and to figure out what Crimean Goths really spoke. The following account is based on the most detailed study available (by the linguist MacDonald Stearns Jr., a former colleague of mine at the University of California, Los Angeles).

To give you a feeling for Crimean Gothic, the table at right lists some of Busbecq's transcriptions (as reconstructed by Stearns) and compares them with the modern German, English, and Frisian words having the same meaning. The first conclusion you'll reach is that Busbecq's informant was indeed speaking some Germanic language, because most of the transcribed words and grammatical endings are close to the corresponding German, English, or Frisian terms. A few Crimean words were evidently borrowed and modified from other languages, because the Crimea was such a linguistic melting pot over the centuries (for example, *telich* 'foolish', from the Turkish *telyq; sada* 'hundred', from the Iranian *sad; Menus* 'meat', from the Hungarian *mén-hús* 'horsemeat'). There is even a Crimean word derived from Latin: *Cadariou* 'soldier' is a legacy of the days when Goths were fighting for or against Roman centurions (*centurio* in Latin). Some of the Crimean words lack a recognizable cognate in any other language (for example, *Marzus* 'wedding').

Even though our sample of Crimean Gothic is so small, it suffices to demonstrate that the language was closer to Wulfila's Visigothic than to either old or modern German—so those Crimeans could not have been descendants of medieval German immigrants. This conclusion is also supported by the similarity of the Crimean and Visigothic words for the numerals '2' through '10'. Citing the Crimean first and the Visigothic second in each case, they are as follows: 2/*tua/twa,* 3/*tria/thria,* 4/*fyder/fidwor,* 5/*fynf/fymf,* 6/*seis/saihs,* 7/*seuene/sibun,* 8/*athe/ahtau,* 9/*nyne/niun,* 10/*thiine/taihun.*

Especially interesting is the Crimean Gothic word for 'egg'. Linguists have deduced that the proto-Germanic language, spoken around 500 B.C. and ancestral to all later Germanic languages, had a sound "jj" between two vowels, which became "gg" in North Germanic languages, "i" in West Germanic languages, and "d" in Visigothic. For instance, the proto-Germanic word meaning 'egg' would have been *ajjaz,* which became *egg* in Old Norse (spelled *ägg* in modern Swedish) but *Ei* in modern German and in Dutch. (We English speakers lost our original *Ei* and now say 'egg', as do Swedes and other North Germanic peoples, because that was one of the many words that our English ancestors borrowed from the Danish invaders who ruled much of medieval England for two centuries.) The surviving portions of Wulfila's translated Bible have nothing to say about eggs, so we can't be certain what a Visigoth said when ordering scrambled eggs for breakfast. However, Busbecq, God bless him, did ask his informant about eggs. Sure enough, the answer was *ada*!—demonstrating that Crimean Gothic had undergone the same "jj"-to-"d" sound shift attested by many Visigothic words. We would never know this if Busbecq had not written down that one word.

But the Crimean Goths were not speaking Visigothic, or even a dialect derived from Visigothic. Among the features of Crimean Gothic unparalleled not only in Visigothic but also in any other preserved Germanic language is the unique formation of the words for '12', '13', and so on (*thiinetua* meaning '10-2'; *thiinetria* '10-3'), as well as the unique formation of the words for '30', '40', and so on (*treithyen* meaning '3rd-10', *furdeitheien* '4th-10'). (Look at the Crimean numerals for '2', '3', '4', and '10' in the list two paragraphs back).

EXTINCT		MODERN	
Crimean Gothic	**German**	**Frisian**	**English**
Apel	Apfel	apel	apple
Boga	Bogen	bôge	bow
Bruder	Bruder	broer	brother
geen	gehen	gean	go
Goltz	Gold	goud	gold
Handa	Hand	hân	hand
lachen	lachen	laitsje	laugh
Oeghene	Augen	eagen	eyes
Rinck	Ring	ring	ring
Salt	Salz	sâlt	salt
schieten	schießen	sjitte	shoot
schlipen	schlafen	sliepe	sleep
Siluir	Silber	sulver	silver
Sune	Sonne	sinne	sun
tzo	Du	dij	thou
telich	närrisch	núver	foolish
sada	hundert	hûndert	hundred
Menus	Fleisch	fleis	meat
Cadariou	Soldat	soldaat	soldier
Marzus	Hochzeit	boaskerij	wedding

In short, in the course of one evening, Busbecq was able to learn enough about Crimean Gothic to convince future linguists that its speakers

were not Germans but a distinct group of Goths related to the Visigoths. Almost surely, they were the direct descendants of the mighty Ostrogoths who settled in the Crimea about A.D. 250, battled the Huns, and conquered Italy. Incredible as it may seem, a few of their descendants were still speaking Ostrogothic some fifteen centuries later, in 1780, at the time of the American Revolution. But before George Washington could complete his second term as president, the few remaining Ostrogoths lost their language and cultural identity, leaving a host of linguistic questions forever unanswerable and extinguishing the last of the Gothic peoples, who had played such a major role in history.

Frisian, the other Germanic language I shall discuss, is of special interest to us speakers of English because it is the language closest to ours, even closer than are German and Dutch. The word for 'cheese', for example, has a familiar sound *(tsiis)* in Frisian but a less familiar sound in Dutch *(kaas)* and German *(Käse)*. (Look again at the table, opposite, for some other Frisian words.) About 2,000 years ago, the Frisians shared the coasts of what are now Denmark, Germany, and the Netherlands with the ancestors of the modern English—the Angles, the Saxons, and the Jutes—who invaded England in the fifth century. When I picked up a book in Frisian, the language struck me as much more reminiscent of the Old English of *Beowulf* than is modern English, because the English, but not the Frisian, language ultimately lost most of its inflectional endings.

After remaining politically independent until the sixteenth century, the Frisians finally became submerged within the Dutch state and German principalities. Today, Germany's remaining Frisian speakers (who live on the country's northwest coast) number only a few thousand individuals, and their two very different dialects (or separate languages) seem doomed to extinction. About 700,000 Dutch people still speak Frisian in the coastal Netherlands.

Many warning signs might suggest that even the large number of Frisian speakers in the Netherlands face the fate of the Goths. The writing of the Frisian language virtually disappeared several centuries ago and was not revived until recently. Since World War II, Frisians have been moving out of Friesland and have become scattered among the majority population, while the Dutch have been moving in. Within Friesland itself, the upper class, the townspeople, and professionals speak predominantly Dutch, while the lower class, the inhabitants of rural areas, and the agricultural population speak predominantly Frisian. The percentage of Frieslanders who speak or understand Frisian has been decreasing for decades, and those who do speak or understand it mostly can't write it (instead they write in Dutch). The Frisian language is becoming ever more "Dutchified" in its vocabulary, its

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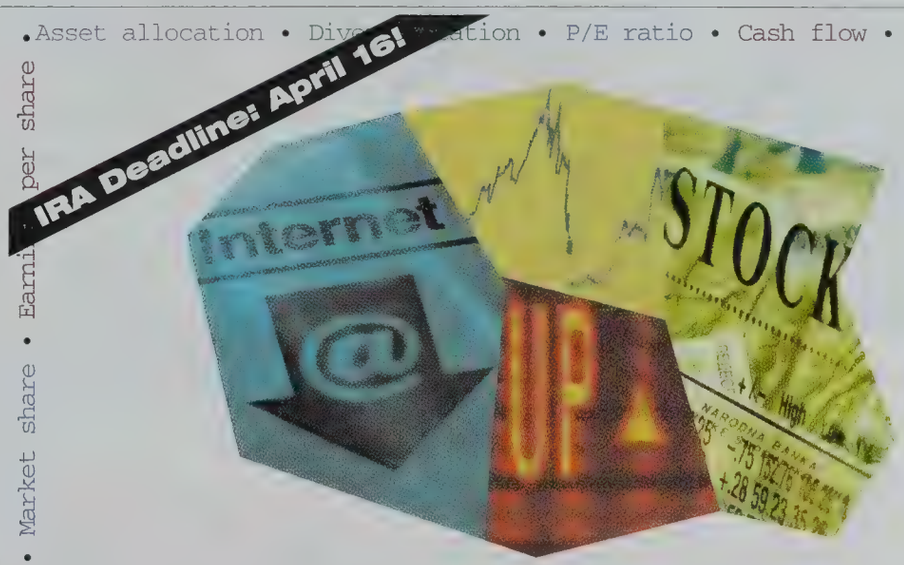

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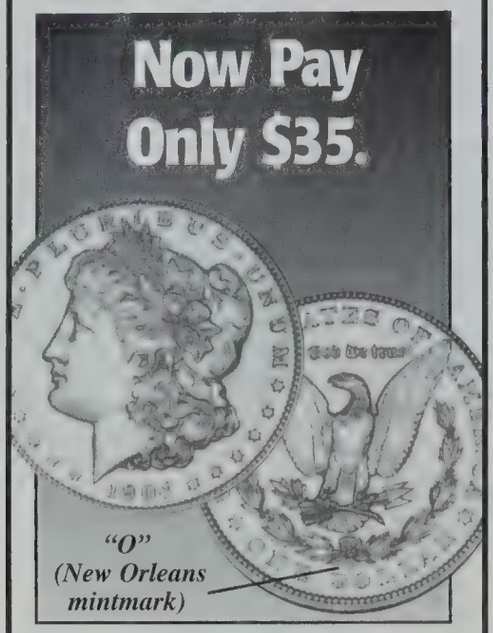

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grammar, and some aspects of its pronunciation.

Recently I found myself in Friesland without having planned the visit. While lecturing at the University of Groningen in the northeastern Netherlands, I was invited by three ornithologists to go for an afternoon's bird-watching. I discovered that Friesland is a distinct province of the Netherlands, with its boundary only fifteen miles west of Groningen. Of my three bird-watching companions, two were Dutch, but one, Theunis Piersma, a well-known authority on migratory shorebirds, was Frisian. Suddenly, there I was in Friesland with a Frisian.

I confess that upon realizing my situation, I felt both curiosity and a little trepidation. I had spent much time in parts of Europe where ethnic divisions provoke vicious conflict, especially Spain's Basque Country and the former Yugoslavia. Were my two Dutch companions welcome in Friesland? Was I entering a depressed area with high unemployment, alcoholism, and a dying language spoken only by old people? Worst of all, was Friesland home to a terrorist movement seeking independence?

Absolutely not. It was immediately obvious that Friesland is peaceful and flourishing, made prosperous by agriculture, industry, and tourism. Road signs are bilingual, in Frisian and Dutch. Everywhere, the Frisian flag flies beside the Dutch flag. Domestic architecture and boats are distinctively Frisian in style. I passed a Frisian wedding procession and visited a Frisian museum. To our two Dutch companions, Theunis spoke Dutch; to a pedestrian whom he asked for directions, he spoke Frisian, which our companions could not understand. The overwhelming sense I came away with was that the Frisians are proud of being Frisian *and* Dutch and are comfortable in their dual identity. Their outlook is reflected in the words of the Frisian national anthem: *It beste lân fan d'ierde!* (The best land on earth!)

How did this happy situation come to be? The key is that the Frisian language is neither outlawed nor merely tolerated as a necessary evil by the Dutch but instead is vigorously supported. As early as 1907, the government began making grants for Frisian lessons in primary schools. In 1955 the teaching of Frisian was permitted in all primary schools, and by 1980 it was required. The government of the Netherlands supports radio and TV broadcasts in Frisian. Frisian writing has been revived, with dozens of books for both children and adults being published in Frisian each year. Since the Bible was finally translated into Frisian in 1943, the number of people using the Frisian language for prayer has increased.

About 1,000 languages are still spoken on the island of New Guinea. Of these, Baso, Kapori, and Mandar have 175, 60, and 20 speakers, respectively.

The visit left me feeling cautiously optimistic about the future of the Frisian language. The Netherlands' public policies seem good both for the Frisian people and for the Dutch state. Even a cynic with zero interest in linguistic diversity would have to admit it: at a relatively insignificant price, the Netherlands has spared itself the problems that many other multiethnic countries have.

I wish I could say the same for the rest of the world. In fact, the situation

of most other minority languages is disastrous. For instance, of the 250 or so original Australian Aboriginal languages, fewer than 100 are still spoken or even remembered by anyone at all, and only half a dozen can boast more than 1,000 speakers. The highest density of languages in the world today is on the island of New Guinea, where approximately 1,000 different languages are still spoken. (Yes, they are really distinct languages, not just dialects, and they fall into dozens of language families, as different from one another as Athabascan languages are from Indo-European.) The median number of speakers per New Guinean language is only 2,000 people, and even the most widely used New Guinean language has only 200,000 speakers. On a recent trip to the island I encountered a North American missionary couple who are devoting their lives to studying the Elopi language and producing an Elopi translation of the Bible. When I asked why they had chosen that language, they explained, "It's because Elopi is such an important language: it has 600 speakers!" That makes Elopi a giant compared with its neighbors Baso, Kapori, and Mandar—spoken by 175, 60, and 20 people, respectively. To deal with this linguistic Babel, the government of Papua New Guinea (the eastern part of the island) adopted English and Pidgin as the national languages but has not promoted instruction in the indigenous languages, all of which face a bleak future.

In North America, of the unknown number of native languages that were spoken when Europeans arrived, only about 200 survive. Most are on the verge of extinction, and many are now spoken by only one or two elderly people. Not one has a secure future. Even Navajo—by far the most widely spoken North American Indian language (with about 100,000 speakers) and one of only two heard in radio broadcasts—is at risk, because many or

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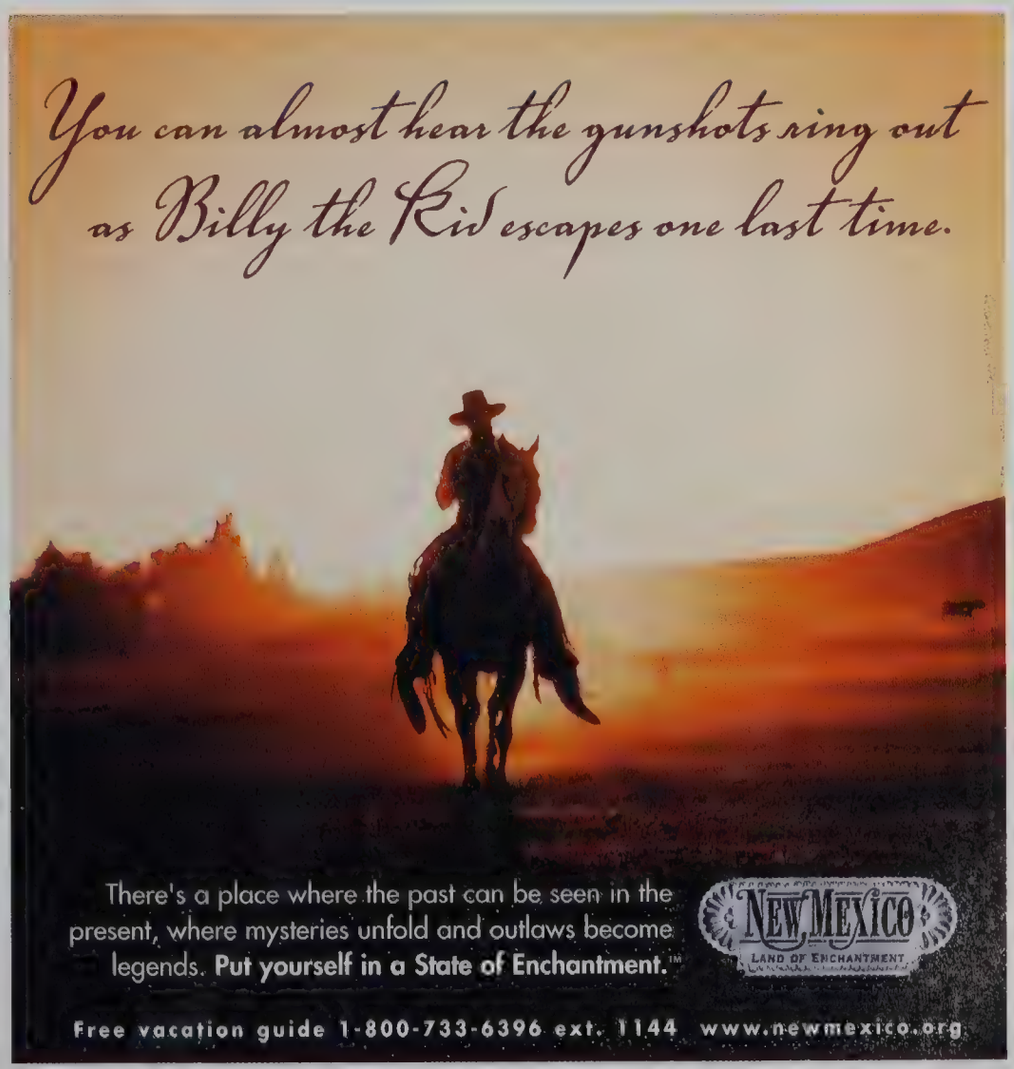
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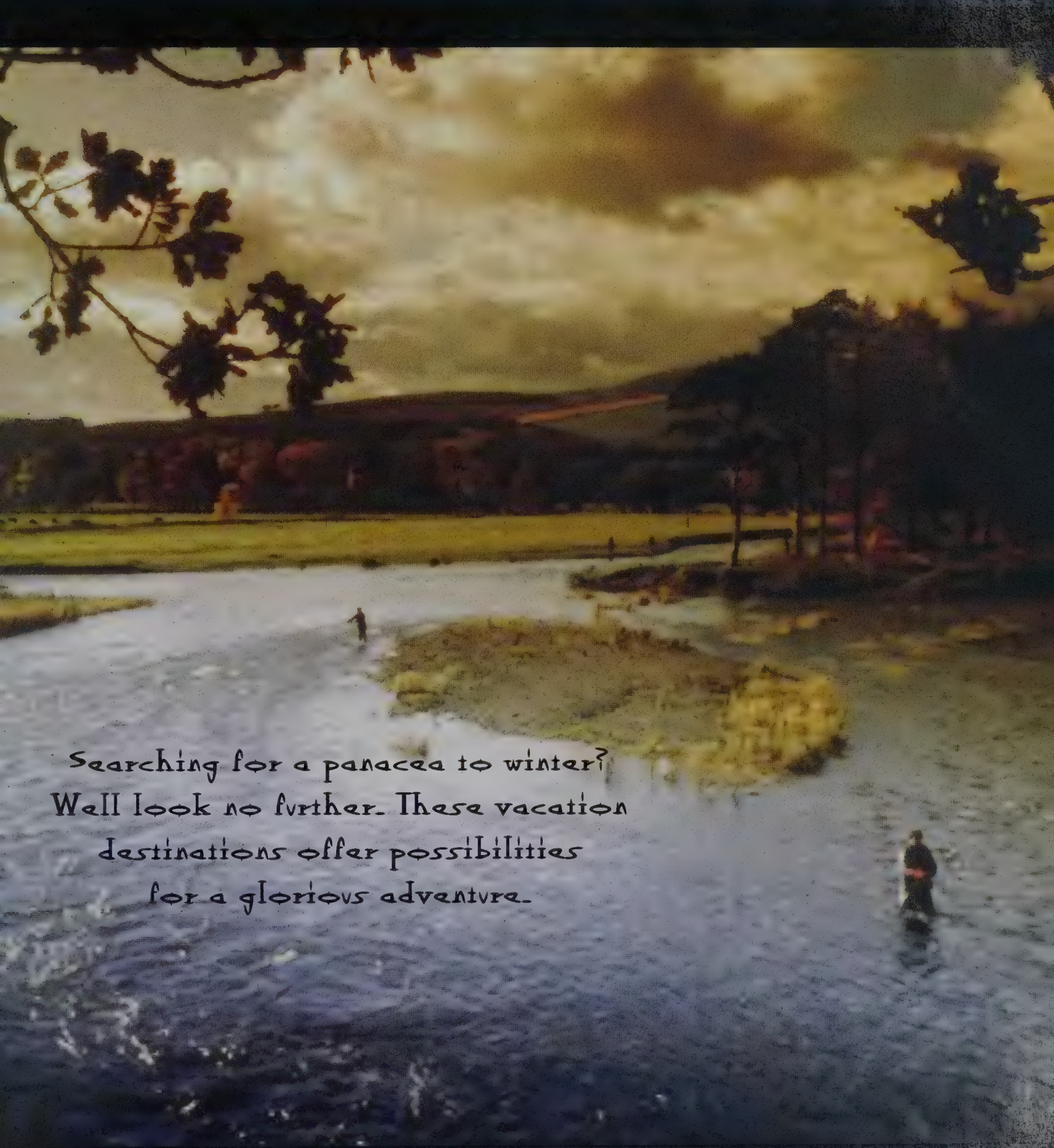
most Navajo children now speak only English.

How Indian languages were reduced to this condition is no secret. For most of the first three centuries after Europeans settled in North America, their main preoccupation was to kill, conquer, drive out, or acculturate Indians. Once the Indian population had been subdued, the U.S. government decided that the best way to "civilize" Indian children was to send them to boarding schools with instruction in English only and to punish severely any of them caught speaking their "barbarous" native tongues. Only in 1967 did our federal government reverse its complete ban on school instruction in any Indian language; not until 1990 did our government decide (in principle) to encourage Indian languages; and not until 1992 did the government appropriate funds for that purpose, in the form of $2,000,000 to foster Native American language studies (that's an average of $10,000 for each of 200 languages). By comparison, our government has spent nearly $20,000,000 to save one endangered North American bird species, the California condor. As an ornithologist, I would be the very last person to begrudge money for the condor; I would merely like to see money for human languages as well.

Why should anyone care about all these vanishing Indian languages? One consideration is their unique value for understanding the history and origins of Native Americans. Many extinct or vanishing Indian languages are the only evidence we have of the long migrations and complex histories of particular peoples. For example, the long-extinct Timucua language of northern Florida, known mainly from the writings of a Spanish missionary living among the Timucuans in the early 1700s, appears to be closest to Indian languages of coastal Venezuela and Colombia, suggesting an ancient back-migration of Indians from South America across the Caribbean to Florida. Our only evidence for a transcontinental migration of Gulf Indians from the area of the U.S. Southeast is the existence of the extinct or nearly extinct Yuki and Wappo languages of northern California (down to ten speakers and one speaker, respectively, a few decades ago), spoken 2,000 miles from the nearest Gulf languages (Choctaw, Creek, and others). With the vanishing of Yuki and Wappo, we are unlikely ever to learn more about them or to uncover the clues they held to great migrations rivaling those of the Goths.

The larger reason that anyone should care about these languages is related to the overall circumstances of Indians in the United States and Canada today—a serious issue for Indian minorities and non-Indian majorities alike. To put it mildly, the situation is not the happy one of Frisians in the Netherlands. Many Indians are caught up in poverty, alienation, health crises, and personal tragedy, which translate into social, political, and economic problems for American society as a whole. Both those Indians who remain poor and those who have achieved some affluence pose challenges to the rest of society, albeit in different ways. What is the role of language in all this? The answer is simple: for North America's 200 Indian language groups, as for every other language group in the world, their language is the vehicle of their culture. No one is demanding that English-speaking Americans be forced to learn Navajo, any more than anyone is demanding that the Dutch of Amsterdam learn Frisian. But all Americans would be much better off if Indians felt unalienated, and proudly and unambivalently Indian and American, just as the Frisians feel proud to be both Frisian and Dutch.

Jared Diamond is a professor of physiology at the UCLA School of Medicine and a research associate in ornithology at the American Museum of Natural History.



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Daily direct flights from the United States fly into Bangkok, known as the City of Angels. The nation's capital since 1782, Bangkok is both a gateway and a principal destination for most travelers. When you fly into this huge city of approximately 10 million people, you'll be struck by the towering high-rise buildings. But once on the ground, the hidden treasures of this wondrous city are revealed. Among the small alleyways that run off the major thoroughfares and the maze of canals that criss-cross the city, Bangkok presents you with a way of life like you've never experienced. Don't miss the Grand Palace and the Temple of the Emerald Buddha, Bangkok's most impressive monument. And wake up at dawn one morning to get a glimpse of saffron-robed monks as they make their early morning alms rounds through the city.

Located on the lower edge of the northern region, some 427 kilometers from Bangkok, is the site of Sukhothai. Founded in the early fifteenth century, Sukhothai was Thailand's first capital. Numerous ruined temples of what was once a large and glorious city are today conserved in Sukhothai Historical Park, an UNESCO designated World Heritage Site. Not far from Sukhothai are the remains of its satellite towns, Si Satchanalai and Kamphaeng Phet. Both have monuments dating from the Sukhothai era, which help complete your understanding of this vital age in Thai history. A good base for exploring Sukhothai is the town of Phitsanulok, 55 kilometers to the east. It is served by regular flights from both Chiang Mai and Bangkok.

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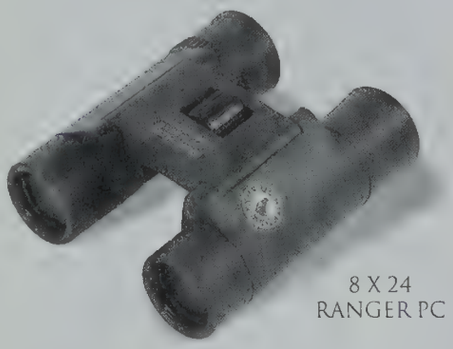

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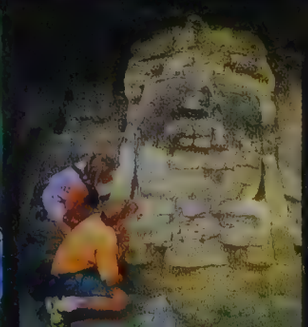

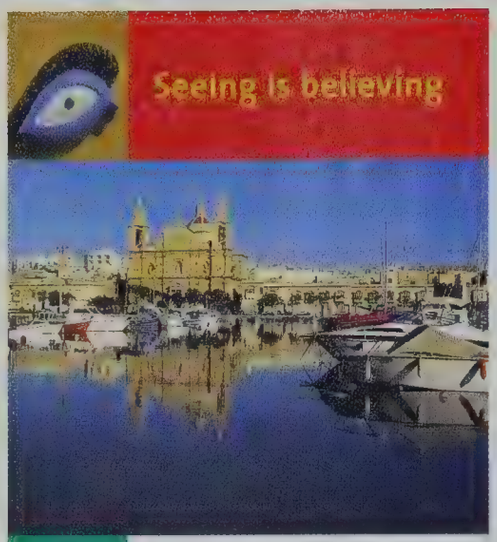

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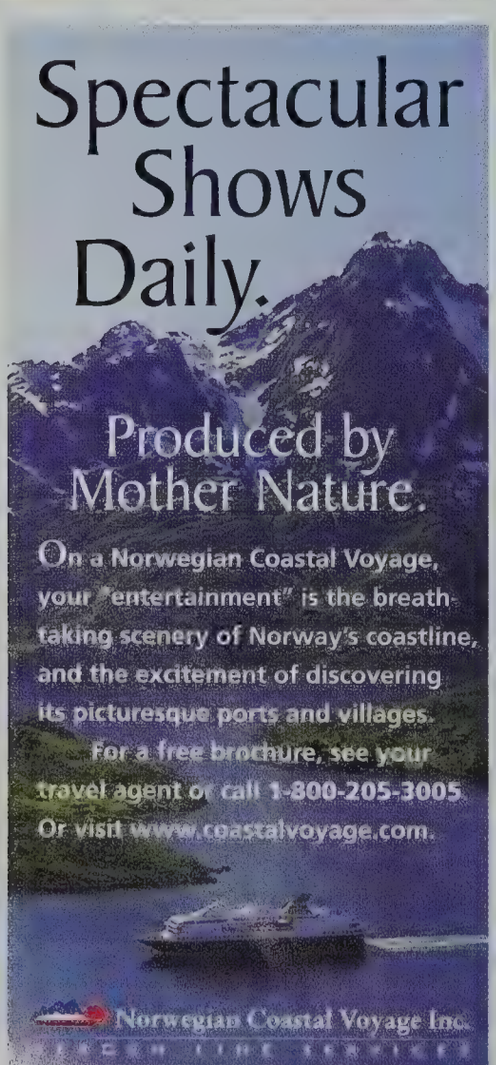
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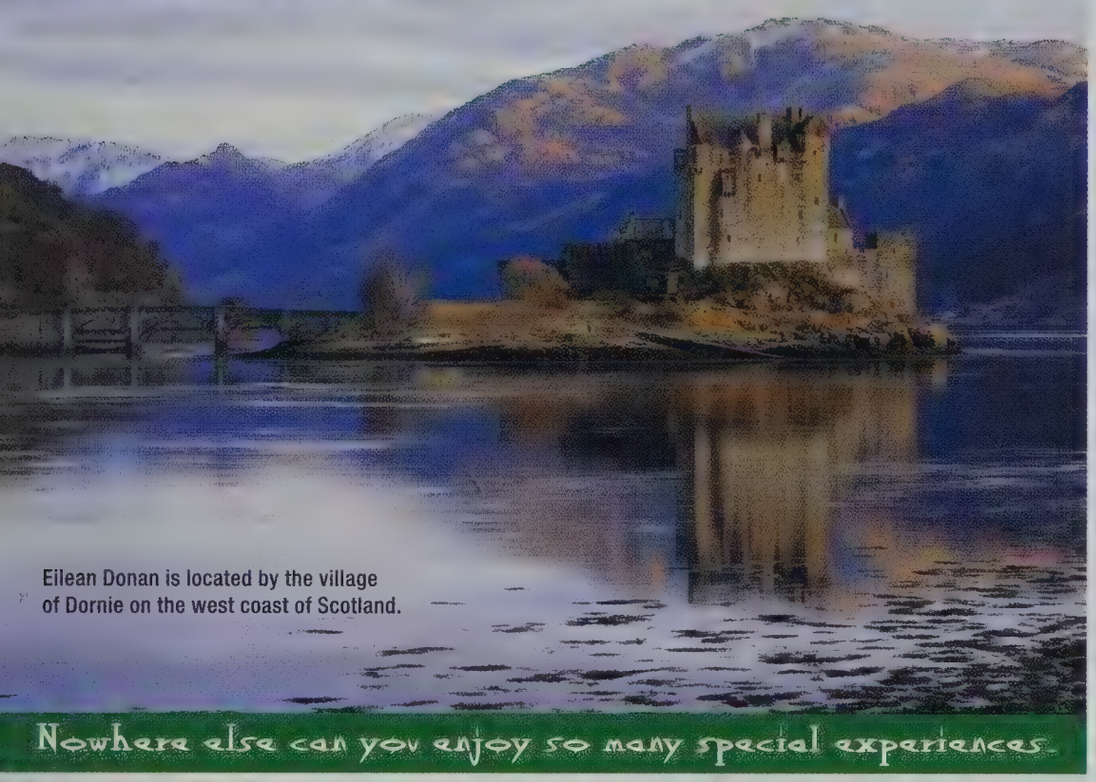

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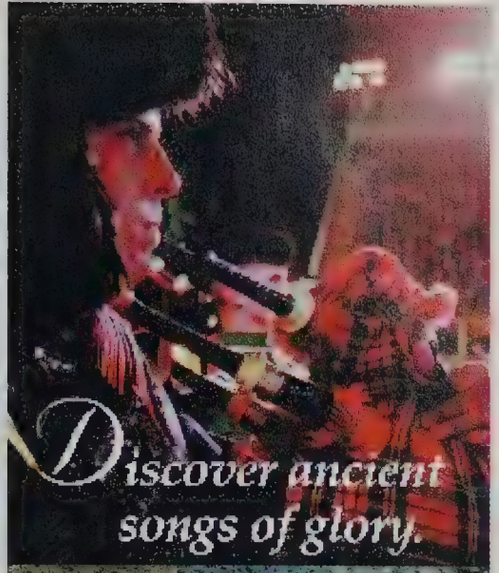

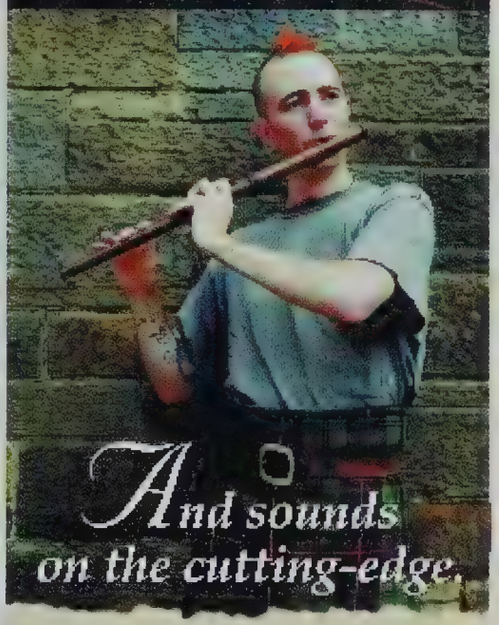

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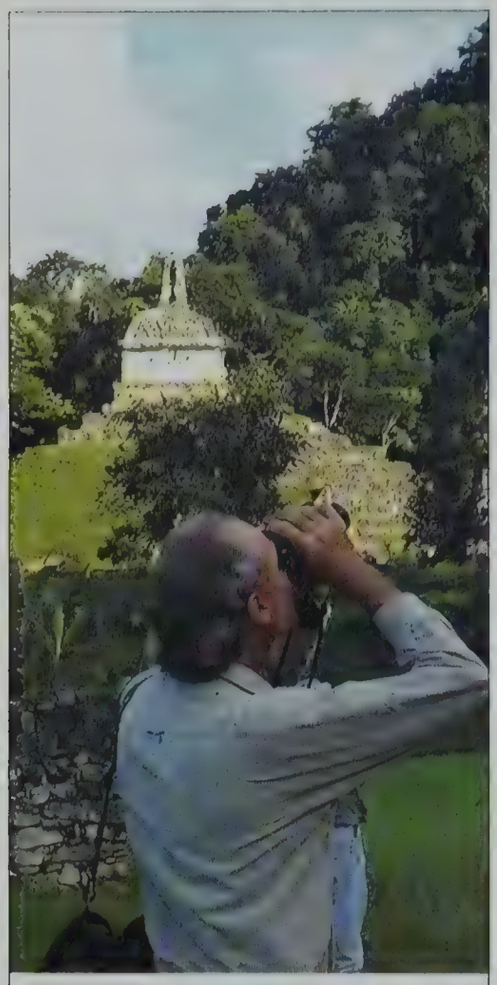

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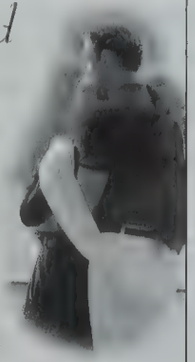

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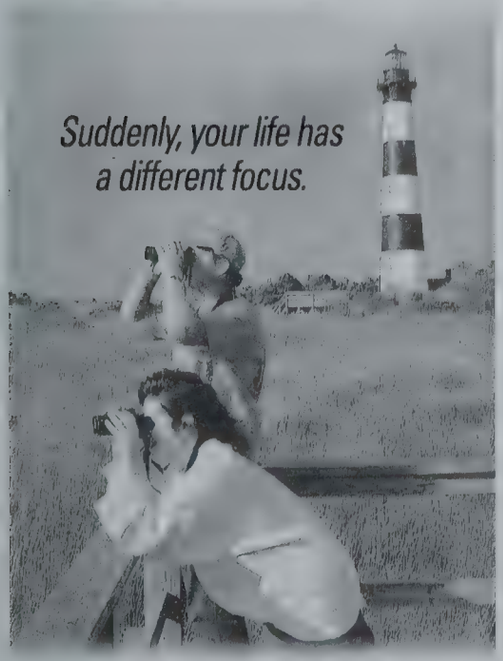
The Outer Banks



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the Bighorn Basin

A modern desert provides clues to an ancient period of global warming.

Story by Scott L. Wing ~ Illustrations by Utako Kikutani

To most people who drive through, hurrying west to Yellowstone National Park, Wyoming's Bighorn Basin is nothing but a vast sagebrush plain crossed by two lanes of blacktop stretching away toward distant snowcapped peaks. Those with their eyes on the horizon may never notice badland hills striped with red and purple, and only those who leave the road will smell pungent, fresh-crushed sage, hear the total silence of the desert at midday, and feel dust as fine as powder between their fingers. Even those who experience the desert may not realize it is a country haunted by time travelers—paleontologists—who pull from the rocks not only fossils but an understanding of how the earth's climate has changed in the past and how plants and animals have responded to those changes. This part of Wyoming contains the world's best record of a period 55 million years ago, when the earth experienced an episode of global warming more rapid than any before, perhaps as rapid as the one we humans are about to cause and experience.

Fifty-five million years ago, parts of Wyoming's Bighorn Basin were lush and swampy. Here, a hippolike *Coryphodon* mother and her young feed on aquatic plants, while a pair of tapirlike *Homogalax* walk among the palmettos at the base of some dawn redwoods.

The Bighorn Basin is roughly 4,000 square miles (about 10,000 square kilometers) of badlands, sagebrush flats, and irrigated fields. Except for a narrow opening to the northwest, it is surrounded by mountains. Like other basins in the Rocky Mountains, the Bighorn Basin formed 60–50 million years ago, during the late Paleocene and early Eocene, as mountains were pushed up on all sides. Fast-moving streams eroded mud and sand from the rising mountains and, slowing as they reached flatter land, spread sediment across the bottom of the basin. Year after year, flood after flood, layers of sediment accumulated until in some areas the pile was more than six miles deep, burying—and preserving—the remains of countless organisms. In the past few million years, this part of the North American continent experienced renewed uplift, the climate became colder and drier, and the vast deposits began to erode rapidly, dissecting the soft rocks into strange and intricate shapes and littering the slopes

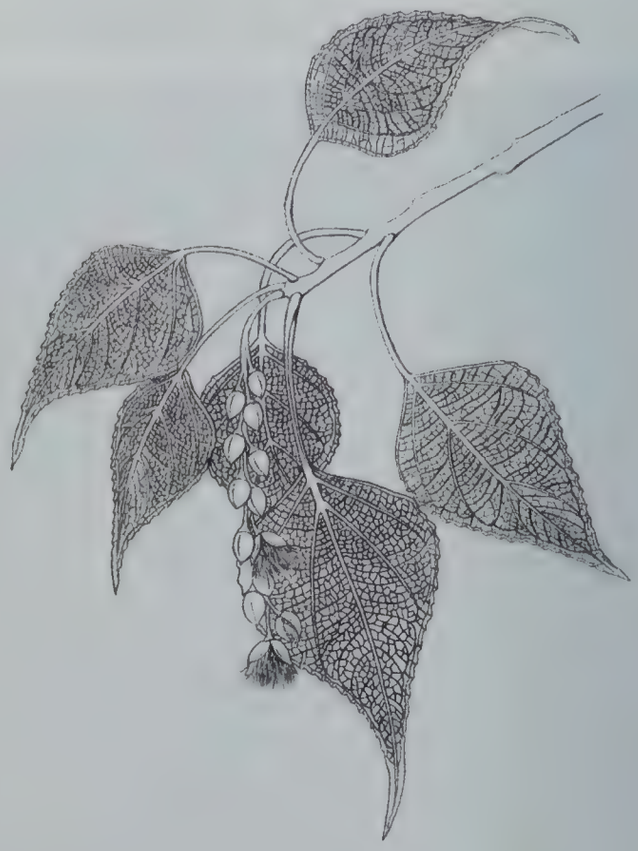
and flats with the fossils once contained inside.

Fossil riches first attracted paleontologists to the Bighorn Basin more than a century ago. Early scientists worked from horseback; photographs of their expeditions show U.S. Army cavalrymen, brought along to ensure safety. In photographs from the early twentieth century, field crews cluster around buckboard wagons or Model T Fords, replaced in more recent photos by weathered pickups and four-wheel-drive vehicles. Traveling in the badlands is still difficult and sometimes dangerous—anyone who has worked long in the basin has spent time digging a stuck vehicle out of a dry creek bed or walked miles to the nearest road to seek help. Stories of such experiences, retold around campfires, remind us of some constants in fieldwork—even if we now locate fossil sites with global positioning systems rather than with cairns and enter data into computers at night as well as into notebooks during the day.

The generations of effort have paid off handsomely. Hundreds of thousands of fossils—mammal bones, leaves, shells—fill the cabinets of museums around the country and even the world. There are fossil pollen grains by the millions. Each fossil reveals something about a once-living organism: a leaf may contain the fossilized trail of an insect larva that tunneled within it for food; the cusps and crests of a mammal tooth bear evidence of the food it was suited to chew; the bones of large land tortoises, soft-shelled aquatic turtles, and alligators show that the ancient climate was warm and that the rivers teemed with life.

Hundreds of thousands of fossils from the Bighorn Basin—mammal bones, leaves, shells—fill museum cabinets around the world.

Evidence of past conditions also comes from the Bighorn Basin rocks themselves. The varicolored bands running across the hills are fossilized soils. The bands' colors indicate such things as the wetness of the original soil, and their thickness provides evidence of the length of time over which they developed. The depth and sinuosity of sandstone deposits reveal the original dimensions and course of ancient river channels. Coal-dark deposits show where the floodplain was especially wet, inhibiting the decay of plant remains by the fungi, bacteria, and arthropods living in the soil. Veterans of fieldwork in the basin are familiar with the colors and shapes that indicate the likely presence of fossils. Bands of red, orange, purple, and light gray (evidence of well-drained soil) often contain fossil bones. Plant fossils occur in several types of rocks, including brown and dark gray layers—all that is left of ancient swamps—and also coarse silt and fine sand layers deposited millions of years ago by overflowing rivers. Sediments containing fossil plants also typically contain the mineral gypsum, which forms large crystals as it weathers out of the rocks. The flashing of gypsum crystals in the desert sunlight can beckon a fossil hunter from miles away.



Poplars growing in the basin's streamside forests had graceful pointed leaves and small hanging flowers, right, much like those of their living relatives.

Taken together, all the evidence yields a picture of the environment and life of the basin during the late Paleocene and early Eocene. The streams—mostly small, slow moving, and gently meandering—were lined with low, natural levees on which grew a variety of trees, including relatives of sycamore, poplar, walnut, and hazelnut. The most common streamside tree was a relative of the katsura tree *(Cercidiphyllum),* a genus restricted today to two species in eastern Asia but once common across the mid and high latitudes of the northern continents. In the understory of these streamside woodlands lived several types of ferns still found in temperate forests, but the areas of open grassland that are so common today were absent. (Grasses had evolved by this time but had not yet become im-

portant forms of vegetation.) A variety of turtles lived in the rivers, along with gar, freshwater clams and snails, crayfish, and alligators. More than a hundred species of mammals roamed the forested floodplains, including some of the earliest primates, dawn horses, the earliest even-toed ungulates (the group that includes deer, pigs, and antelope), early true carnivores, and other mammals that have no extant close relatives (see "Wyoming's Garden of Eden," page 55). Among the birds was *Diatryma,* a six-foot-tall relative of today's cranes.

Plants of the lower, wetter floodplains included dawn redwood *(Metasequoia),* a Chinese relative of bald cypress *(Glyptostrobus),* alder, a relative of witch hazel, and more than a hundred less-common species. Also flourishing in these swamp forests were relatives of a number of living, mostly tropical or subtropical plant families, including palms, cycads, tree ferns, gingers, magnolias, laurels, and hibiscus.

My work in the Bighorn Basin has focused on the plant fossils and the story of climatic change that can be learned from them. Even after nearly thirty years of fieldwork in the area, I still find it exciting to collect fossils of subtropical plants in a high desert where winter temperatures sometimes drop to -40° F (-40° C). One indication that the global climate has cooled radically in the past 50 million years comes from the identification of fossil plants whose living descendants are restricted to relatively mild parts of the planet. But the shapes and sizes of leaves have their own story to tell. Today, for example, plants with smooth-margined leaves (such as magnolias) are more diverse in warmer climates; plants with toothed or jagged leaf margins (such as elms or birches) make up a larger proportion of the species in cooler areas. We don't fully understand the reasons for this difference, although we do know that the tissue in a leaf's marginal teeth matures more quickly and begins to photosynthesize earlier than its other parts—a developmental schedule that may be advantageous for plants in cool climates with short growing seasons. Water evaporates faster from the teeth, however, and in warmer, drier climates the cost of lost water may outweigh the benefit of a photosynthetic head start.

The size of a leaf, too, can inform us about past climatic conditions. The larger the leaf, the more quickly it heats up—and loses water. As a result, plants of drier climes tend to have smaller, more water-efficient leaves. Extrapolating from the relationships between leaf size and shape in living plants and contemporary levels of precipitation and temperature, scientists can use the sizes and shapes of fossil leaves to infer past levels of precipitation and temperature. The estimated mean annual temperature in the Bighorn Basin during the Paleocene and early Eocene varied from about 50 to 68° F (10–20° C). Winter frosts, if they occurred at all, were short-lived and mild. The ground never froze.

Other clues to past temperatures exist in the ratio of two oxygen isotopes: ^{16}O and ^{18}O. These isotopes occur in rainwater and therefore also in the surface water that animals drink and that helps form soil minerals. The warmer the climate, the warmer the rain and the higher the ratio of ^{16}O to ^{18}O. Knowing this, scientists can estimate the temperature of ancient rain from the ratio of isotopes trapped in fossil mammal teeth and soil minerals.

CHIP CLARK

A common tree in Wyoming's ancient swamps was *Glyptostrobus,* in the bald cypress family. A fossil, below, shows a branch with scalelike leaves and a cone at the tip.

KENNETH D. ROSE

A view of the Bighorn Basin. When looking for fossils, paleontologists are guided by the shapes and colors of the basin's rocks. Red and orange bands are fossil soils that often contain mammal bones.

The results of calculations using the isotopic method are generally in agreement with those based on studying leaves. Both show a complex pattern. Temperatures warmed fairly quickly during the last million or so years of the Paleocene (from about 56 to 55 million years ago). Then, about 55 million years ago—near the boundary of the Paleocene and the Eocene—they warmed even more, and very rapidly. Detailed analyses of cores taken from the ocean bottom suggest that this warming took place over about 10,000 to 20,000 years—very fast for such a large change. Over the course of the following 100,000 to 200,000 years, the moderate climate seen through much of the late Paleocene and early Eocene returned. Later in the early Eocene, temperatures cooled and then warmed once more (reaching the highest temperatures seen in the past 65 million years).

The release of enormous amounts of methane gas from the seafloor may have contributed to a period of rapid global warming 55 million years ago.

In the Bighorn Basin, evidence of the sharp warming near the time of the Paleocene-Eocene boundary can be found in several exceptionally thick, greatly weathered fossil soils. It is in these layers that fossils of odd-toed ungulates, even-toed ungulates, and primates first appear. These new mammals arrived simultaneously in Europe, and at the same time a number of hard-to-explain global events occurred: Single-celled seafloor organisms went extinct in record numbers. Warmth-loving plankton appeared in middle- and high-latitude oceans, such as the North Atlantic and the oceans surrounding Antarctica. Ocean surface waters at high latitudes warmed by as much as 14° F (about 8° C). The ratio of light to heavy carbon isotopes increased dramatically in rocks and fossils. (Like oxygen, carbon has two common stable isotopes: light, or ^{12}C, and heavy, or ^{13}C. Many organisms use ^{12}C preferentially in their metabolism, because it's more chemically reactive, so an increase in the amount of ^{12}C in rocks and fossils could indicate that something had caused the release of large amounts of carbon previously used by living things.)

What was responsible for the rapid warming 55 million years ago, and did it perhaps have anything to do with these other events? We can pretty much rule out one known cause of rapid climate change—the melting and growth of ice sheets—because polar ice caps and continental ice sheets probably didn't exist during the Paleocene and Eocene. Recently, however, scientists proposed a new the-

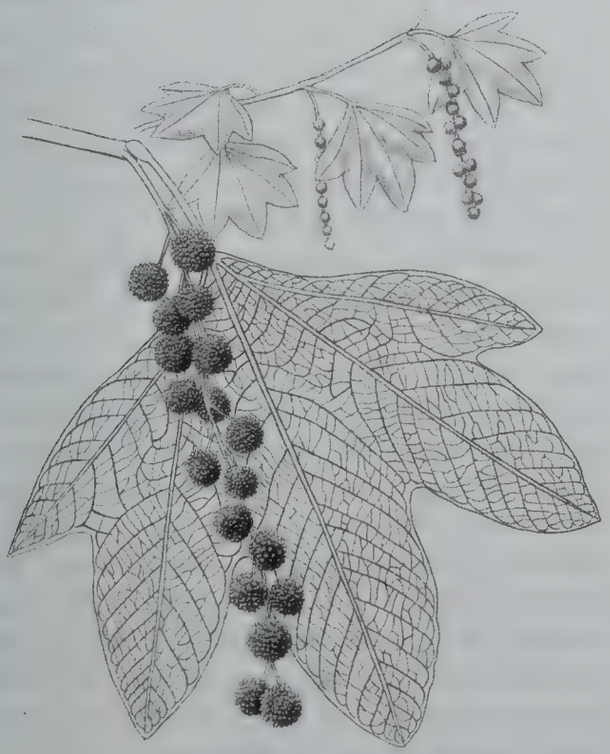
ory to explain the Paleocene-Eocene climate change: the melting of methane ice on the seafloor.

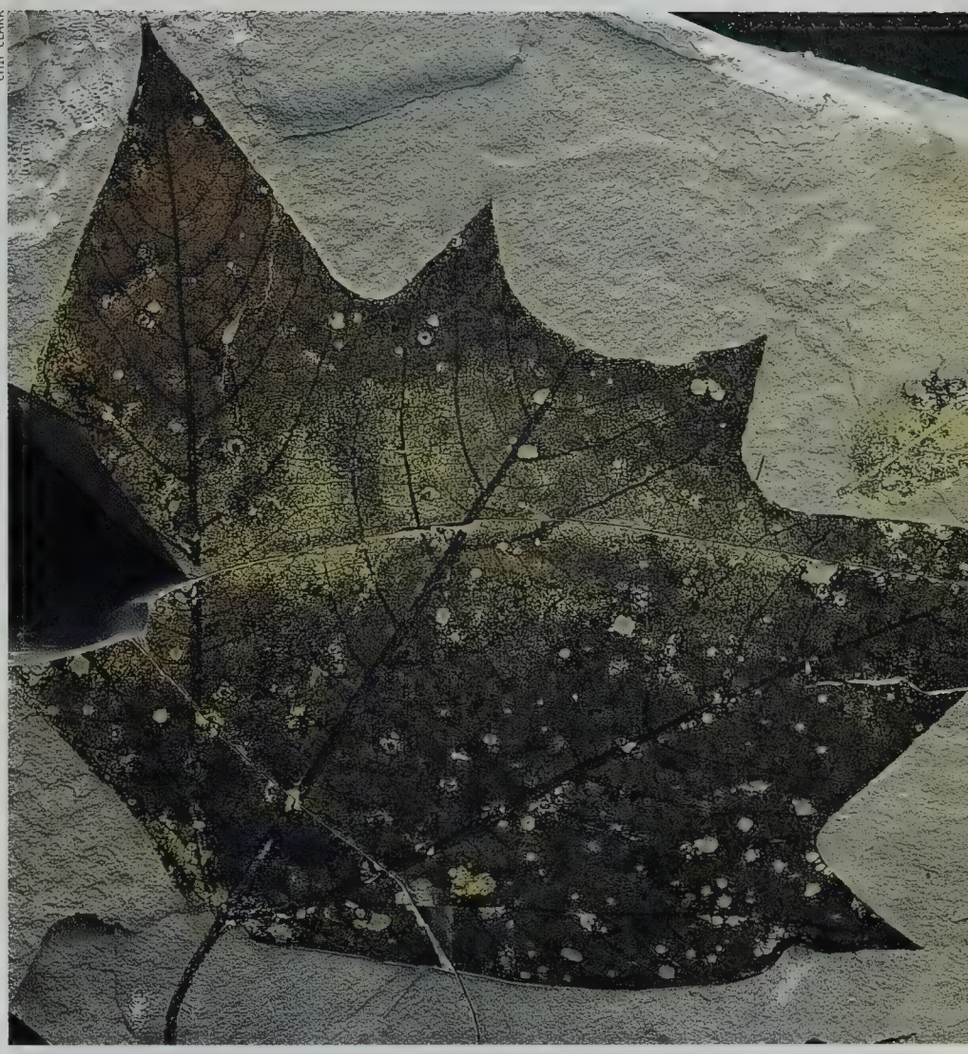
Microbes that feed on organic material raining down to the ocean bottom produce methane gas as a by-product of their decay. When this gas combines with water under the high pressures and low temperatures found on the seafloor, it can form ice-like compounds called clathrates. According to the new theory, rising ocean temperatures, an earthquake beneath the seabed, or some as yet unknown mechanism triggered the release of enormous quantities of methane that had been locked up in clathrates. This would have led to further warming of the atmosphere and the ocean (methane is a powerful greenhouse gas), encouraging the additional release of seafloor methane in a potentially self-reinforcing process. The released methane would have reacted rapidly with oxygen, producing carbon dioxide and water vapor (both powerful greenhouse gases), and both of these would have made their own contributions to the warming.

Eventually, however, much of this carbon dioxide would have reacted with rocks during the process of chemical weathering or been used by plants in photosynthesis. Much of the water vapor produced by the methane-oxygen reaction would have rained out of the atmosphere. The result of these processes would have been a gradual return to the earlier atmosphere and climate.

The methane theory illuminates more than just the increase in temperature that occurred 55 million years ago. A by-product of decaying organic matter, methane has a high ratio of light to heavy carbon, which could explain why geochemists have found more ^{12}C in rocks from that period. In addition, carbon dioxide that formed when methane reacted with oxygen that was dissolved in seawater or contained in the atmosphere could have changed the chemistry of the deep-sea environment, making it more corrosive. This, plus the reduced amount of oxygen in the water, would help account for the extinction of bottom-dwelling microorganisms. Moreover, the temporarily increased rainfall and higher temperatures explain the highly weathered soils seen in the Bighorn Basin rocks of this time.

Warming probably also made high-latitude land bridges across what are now the Bering Strait and the North Atlantic Ocean more hospitable to mammals, enabling intercontinental migration and explaining the animals' sudden appearance in the basin. Unfortunately, we have found no fossil plants from the warmest period, but fossils from just after the Paleocene-Eocene boundary show that only a few new types of plants (including several ferns) appeared at this time. The modest change in vegeta-





The lobes and veins of a fossilized *Macginitiea* leaf, above, show that it belongs to the sycamore family. An Eocene insect chewed a semicircular cut in the leaf's central lobe. Left: An artist's rendering of an intact *Macginitiea* leaf shows male and female flowers as well.

tion is curious, because plants are famously sensitive to climate change. Perhaps warm-climate (probably evergreen) species found it difficult to adapt to the polar nights on the high-latitude land connections. Or perhaps plants were slow to disperse because their seeds did not germinate and grow well in the shade of preexisting dense vegetation.

The warming that took place around the transition from the Paleocene to the Eocene demonstrates that greenhouse climates can come and go in a geological blink and that lasting rearrangements of animal life may accompany the changes. Although the temperature increase reversed within a geological moment, the effects on the mammalian community were permanent. The lineages that appeared during this period went on to dominate faunas for millions of years, largely replacing those that had been important on the northern continents for the previous 10 million years. Descendants of some of these immigrants, such as deer and pronghorns, are still dominant in this area today.

CHIP CLARK

Common in the Tropics today, *Salvinia* was also an abundant aquatic fern during the Eocene. Its small, hairy, oval leaves floated on the water's surface.

The fossils from the Bighorn Basin tell a story about how plants, animals, and whole ecosystems respond to long-term shifts in global climate.

The lack of dramatic change in vegetation raises questions about how successfully plants can respond to warming climates, especially if they disperse slowly. Most of our knowledge about the issue has come from studying the recent geological past (the past 20,000 years), during which glaciers retreated from the northern continents. Plant populations altered their distributions very rapidly during this period, sometimes averaging more than half a mile (about one kilometer) a year. For those who hope this means plants will be able to cope with rapid climate change in the future, the message is not so simple. The difference between plant response to the Paelocene-Eocene warming and to the last deglaciation suggests that vegetation can't always respond quickly. (It may, for example, be easier for seeds to establish themselves on the new ground exposed by retreating glaciers.) Moreover, the past makes an imperfect predictor because of the complicated effects of human actions—including habitat fragmentation, introduction of nonnative species, and conservation efforts. These actions may skew the odds in favor of some plants and against others.

Much remains to be learned about climate change during the Paleocene and Eocene. Our current knowledge has come from the efforts of hundreds of scientists—paleontologists, geochemists, climate modelers, and oceanographers—working all over the globe. New methods of analyzing fossils and sediments allow us to ask new questions. For instance, we may soon have reliable estimates of the concentrations of carbon dioxide in the atmosphere during this time. As work continues in the Bighorn Basin and elsewhere, our static snapshots of individual reconstructed moments from the past are being transformed into a motion picture revealing the responses of ecosystems to long-term shifts in global climate and regional environments. In effect, scientists are discovering a movie about life during the last great warming.

This may be a movie worth watching. The past decade was by far the warmest since the beginning of good record keeping. Average global temperature is now higher than in any previous period for which written documentation exists. Present levels of atmospheric carbon dioxide are 30 percent higher than preindustrial levels and will continue to increase rapidly if current trends in the human generation of carbon dioxide continue.

Earth's future may well hold climates warmer than any experienced in the last several hundred thousand years. But we know from work in the Bighorn Basin and elsewhere that greenhouse climates are not without precedent in our planet's history. If our climatic future looks even a little like the greenhouse past, then the paleontological and geological work done in the Bighorn Basin is not just an exercise in intellectual curiosity. The horse-mounted paleontologists of the 1880s probably wouldn't have been surprised to learn that their successors 120 years later were still finding fossils in the basin, but they would likely have been astonished that our minds are as much on the future as on the past. □

Wyoming's Garden of Eden

The rich fossil record from the early Eocene Bighorn Basin includes the remains of the most ancient primates, hoofed animals, and carnivores.

Story by Kenneth D. Rose
Illustration by Utako Kikutani

Today Wyoming's Bighorn Basin, home to pronghorns and prairie dogs, coyotes and rattlesnakes, is nearly a desert. But close your eyes and imagine a scene in this same region 54 million years ago, after a time of rapid and dramatic warming. The ancient Bighorn is a subtropical lowland floodplain, lush with vegetation and teeming with animal life. Many of the mammals are new immigrants to the basin, and some look, if not modern, then strangely familiar. It is just after daybreak, and a group of primates forages peacefully among the trees bordering a pond. Resembling lemurs, they leap from branch to branch in search of fruit and nuts. Nearby, raccoon-like animals climb through the trees; occasionally one stops to groom itself, using its front teeth. On the forest floor, two rabbit-sized, hoofed animals hop through the low underbrush. Browsing on herbs and shoots, they are apparently oblivious to a herd of dawn horses, no bigger than beagles, running by. Suddenly the serenity is broken as a giant bird, recalling the mythological roc, barges through the brush, creating a momentary panic among the dawn horses. As they scatter, they are startled by a bear-sized *Pachyaena* with a monstrous head and threatening jaws. This time, however, the *Pachyaena* merely wants to scavenge a carcass. Some distance away, a pair of tapirlike animals ambles through a swamp while a hippolike *Coryphodon* and its baby stand in the still waters and feed on aquatic plants.

For those of us who study Eocene mammals of the Bighorn Basin, such scenarios are easy to envision, for the life and death of the region's ancient inhabitants are recorded in the fossils that abound in the badlands. Over the past 120 years, paleontologists working there have recovered remains of more than 200 species of mammals. These fossils not only tell us what early denizens of the basin looked like but also provide information about what they ate, how they moved, how they were related to one another, and what habitats they lived in. Tooth marks on bones reveal attacks or scavenging by ancient carnivores; some bones are even broken in ways that suggest an individual was killed by an owl. Bones that lay exposed long after the animals died often have characteristic gnaw marks left by rodents, or cracks due to drying.

NORMAN BARKER

Well-preserved, articulated, and nearly complete, a skeleton of *Chriacus*, below, indicates that this raccoonlike mammal was rapidly buried after its death.

Each summer for the past twenty years, often in collaboration with Tom Bown of the U.S. Geological Survey, I have led a group of students and associates to the Bighorn Basin to collect fossils of early Eocene vertebrates. Of particular importance to paleontologists, the early Eocene—from about 55 to 52 million years ago—is the interval when many of the modern orders of mammals, including our own, first appeared. The more than 50,000 specimens we have amassed from the 2,000- to 3,000-foot-thick sediments of the basin's Eocene outcrops now reside at the Smithsonian's National Museum of Natural History. Our collection, together with the others unearthed from the Bighorn Basin, con-

When Wyoming was warm: Ancient animal life abounds at an early Eocene pond and in surrounding woodland.

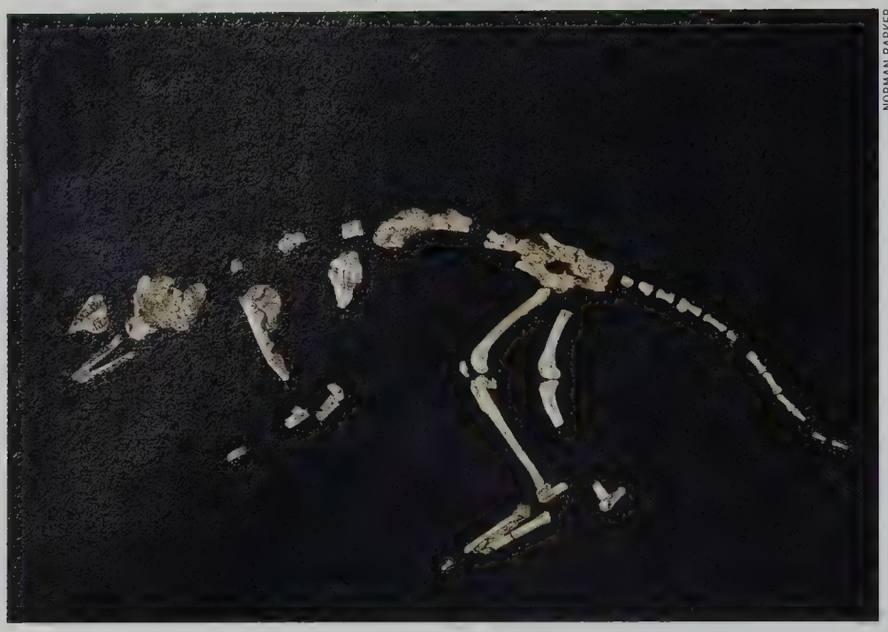
stitutes the world's richest and most diverse record of the vertebrate life that existed during the warmest climatic interval since the demise of the dinosaurs. These specimens also provide evidence—some of the most detailed in the entire vertebrate fossil record—of how certain animals evolved, in many cases showing a continuous, gradual transformation from one species to another through time.

Like most Eocene fossils, those in the Bighorn Basin are almost always fragmentary, consisting mainly of isolated bones, jaw fragments, and teeth. While teeth can tell us a lot, other parts of the skeleton are essential if we are to understand many other aspects of these mammals' lifestyles and relationships. One of the main goals of our expeditions has been to find mammal fossils other than teeth and jaws. By concentrating on ancient soils whose color and other sedimentary features indicate that they are likely to preserve skeletal material, we have been rewarded with hundreds of partial skeletons of nearly fifty kinds of mammals. These include the most ancient primates, hoofed animals (ungulates), carnivores, and rodents, as well as many extinct groups. We can now re-create the mammalian life of the Eocene in considerable detail.

Impressive numbers of the lemurlike *Cantius* inhabited the newly formed basins and ranges of the Rocky Mountain region during the early Eocene. Thousands of its jaws and hundreds of isolated bones have been found in the Bighorn Basin. So far, however, only three partial skeletons have been unearthed. From these we know that *Cantius* was one of the earliest of the primates, the group that now includes monkeys, apes, and humans. It was an agile climber, with long hind limbs for leaping, nails on its digits, and a grasping big toe. Compared with other early Eocene mammals, *Cantius* also had a large brain and relatively large eyes. In all these characteristics, *Cantius* resembles modern primates and differs from the so-called archaic primates that were common in the Paleocene, the 10-million-year period after the dinosaur extinction and just before the Eocene.

The change in mammal life was abrupt and profound: in the early Eocene, half the individuals in many Bighorn Basin animal communities were immigrant species.

Also adapted to life in the trees was *Chriacus,* a raccoonlike member of the arctocyonids, a now-extinct group that probably gave rise to the modern ungulates. In contrast to the feet of present-day hoofed mammals, which are specialized for ground locomotion, the foot structure of *Chriacus* shows that it could climb up and down trees with facility. By turning its feet around and gripping the tree trunk with sharp claws, it could descend headfirst,



NORMAN BARKER

Diacodexis, above, had long, slender hind limbs and joints specialized for running and hopping. Despite its rabbitlike features, *Diacodexis* is the oldest known member of the group that includes today's pigs, camels, and deer.

in squirrel fashion. This creature was one of the first mammals we know to have had long, narrow lower incisor teeth arranged in the shape of a comb, similar to the tooth comb of modern lemurs. Microscopic grooves on these teeth confirm that *Chriacus* used them to groom its fur. Its molars indicate that it was an omnivore whose diet most likely included fruit, nuts, and even small animals, although it was probably no threat to the similar-sized *Cantius*. The primate and its young would have had more to fear from early tree-climbing carnivores known as miacids, from predators called creodonts, and from a variety of terrestrial meat-eaters.

While none of the true carnivores (those related to living dogs and cats, for example) got much larger than a coyote, some of the early Eocene creodonts were bigger than wolves. But even they were dwarfed by the formidable *Pachyaena,* a ground-dwelling cousin of the earliest whales, whose head reached the size of a Kodiak bear's. *Diatryma,* a six-foot-tall flightless bird with a foot-and-a-half-long head, would have been equally intimidating. Both of these creatures, which are best known from the Bighorn Basin, appear to have been primarily carnivorous, although we cannot be certain if they were active predators or merely scavengers.

Unlike many of their hoofed descendants, none of the early Eocene ungulates was a grazer. Grassland habitats were not to become widespread for millions of years.

The bones of another Bighorn Basin mammal, *Diacodexis,* show it to be the oldest and most primitive of the even-toed ungulates. (We divide hoofed mammals into two main groups: the artiodactyls, having an even number of toes, and the perissodactyls, having an odd number of toes.) *Diacodexis* was thus the forerunner of all the living artiodactyls, a varied group that includes pigs, hippopotamuses, camels, giraffes, sheep, and deer. *Diacodexis* itself probably looked and moved something like the diminutive chevrotain, or mouse deer, of Asian forests. Its molars, which have low, rounded cusps, suggest a diverse herbivorous or omnivorous diet, but while its teeth are generalized, *Diacodexis*'s skeleton is strikingly specialized for its time. Its small size and elongated, slender legs—with the hind limbs markedly longer than the forelimbs—would have given the animal a somewhat rabbitlike appearance and way of moving, although it is not related to rabbits. Unlike the flexible joints of climbing mammals, *Diacodexis*'s joints restricted movement to a hinge motion in a fore/aft plane. The feet had four functional toes, the two central ones being larger and of equal size. A delicate hoof tipped each digit. These features would have made *Diacodexis* one of the swiftest runners of its day. But given its probable forest habitat, diet, and ability to hop over branches, *Diacodexis* may have used its speed only occasionally, to escape predators.

Remains of odd-toed ungulates are among the most common Eocene fossils found in the Bighorn Basin. Jaws of *Hyracotherium* (or *Eohippus,* the dawn horse) have emerged by the thousands, and its skeletons are more numerous than those of any other mammal. Less common, and found only recently, are skeletons of *Homogalax* and other ancient relatives of the present-day tapirs of South America and Asia. The tapiroids were generally larger than dawn horses, the biggest being sheep-sized. Both *Hyracotherium* and *Homogalax* were well adapted for running, but the tapiroid was more primitive in this regard, suggesting that it more closely resembled the ancestor of all odd-toed ungulates than does *Hyracotherium.* The hind feet of both animals bore just three toes; the front feet had three plus a greatly reduced fourth digit. All the toes were equipped with a small, broad hoof.

The molars of *Hyracotherium* and *Homogalax* were low-crowned, like those of *Diacodexis,* but had multiple shearing crests, a specialization for processing vegetation. Unlike many of their hoofed descendants, neither they nor any other early Eocene ungulate was a grazer. Grassland habitats were not to become widespread for millions of years. The

teeth of early Eocene ungulates lacked the high crowns and elaborate chewing surfaces that allow grazers to grind grasses, which contain abrasive silica. These animals were probably browsers that fed on softer plant material, leaves, and shoots.

Not all the plant eaters in the Bighorn Basin Eocene mammal community were related to present-day ungulates. The most abundant large herbivore was *Coryphodon,* a ponderous, cow-sized member of an extinct group known as pantodonts. Like tapirs and pygmy hippopotamuses today, *Coryphodon* probably preferred wet forests or swamps, where it used its tusklike canines and broad, crested molars to feed on vegetation.

The newcomers that arrived in association with the warming at the end of the Paleocene—especially primates and ungulates—significantly altered the composition of the Bighorn Basin's mammal communities. Paleocene faunas were dominated by what we refer to as archaic mammals: condylarths (archaic ungulates), archaic primates, small rodent-like multituberculates, pantodonts, and others. While all these groups survived into the Eocene, most were substantially reduced in numbers and diversity. The change in mammal life was not only abrupt, it was profound: fossil evidence shows that in the early Eocene, half the individuals in many mammal communities belonged to immigrant species. This faunal turnover at about 55 million years ago took place not just in the Bighorn Basin but across all the northern continents. The results have been long lasting. Even- and odd-toed ungulates are the predominant large mammalian herbivores in most of the world today, and primates populate rainforests from South America to Africa and Asia. One thing seems clear: the immigrations were tied to global warming. But had we been there 55 million years ago, we could hardly have predicted the eventual ecological impact of that warming event. Only through paleontology have we gained the hindsight to appreciate the potential consequences of widespread climate change. □

In 1896 vertebrate paleontologist Walter Granger photographed the fossil-rich Wyoming badlands, below.

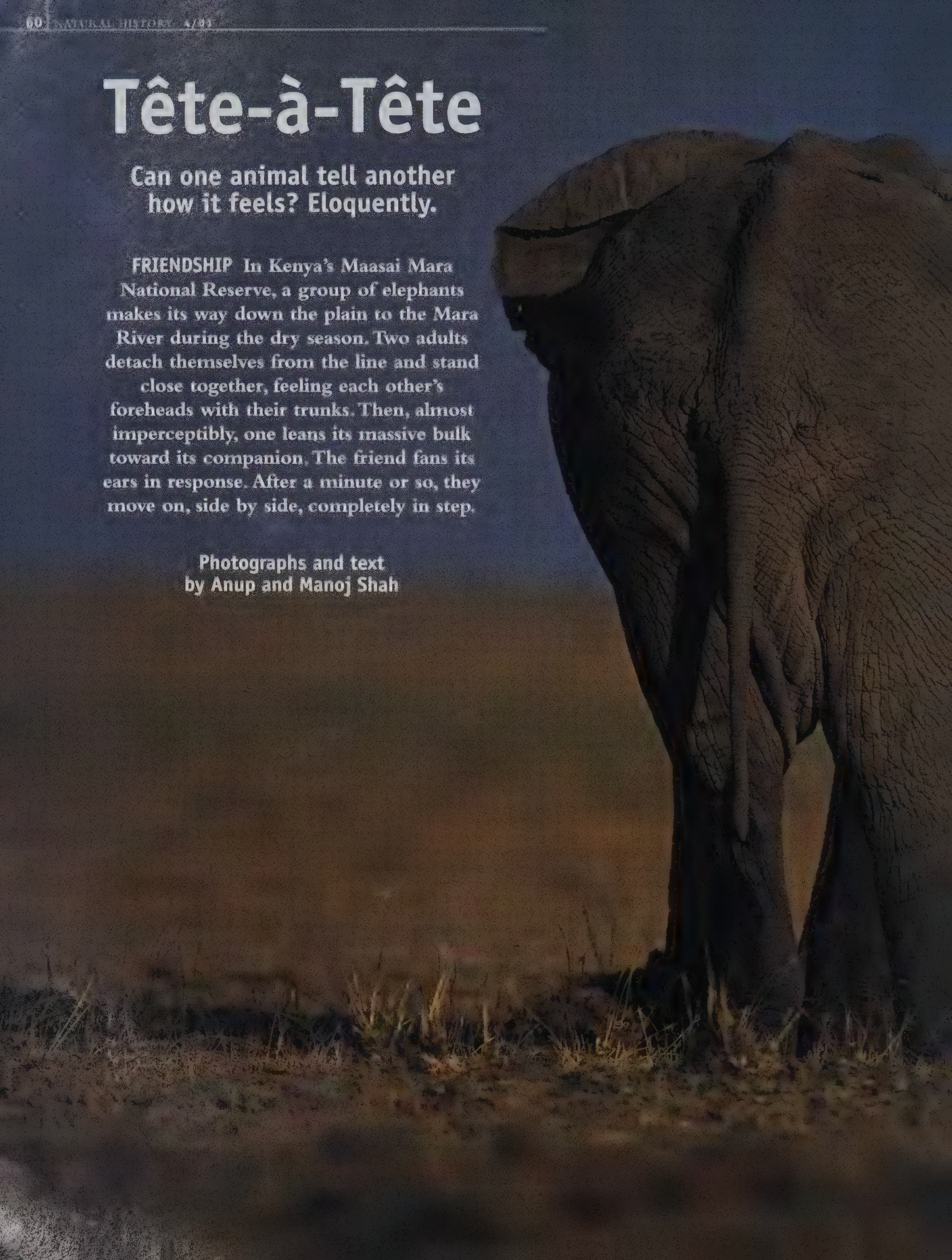
WALTER GRANGER; AMNH

Tête-à-Tête

Can one animal tell another how it feels? Eloquently.

FRIENDSHIP In Kenya's Maasai Mara National Reserve, a group of elephants makes its way down the plain to the Mara River during the dry season. Two adults detach themselves from the line and stand close together, feeling each other's foreheads with their trunks. Then, almost imperceptibly, one leans its massive bulk toward its companion. The friend fans its ears in response. After a minute or so, they move on, side by side, completely in step.

Photographs and text
by Anup and Manoj Shah



RIVALRY At the Musiara swamp in the Maasai Mara, a mated pair of warthogs feed side by side. A solitary male forages nearby. Eventually the female leaves her mate to drink from a small pool of water. The lone boar follows her, but before he reaches the pool, the other male calmly trots over. The two size each other up, then butt heads in what seems like a highly formalized ritual rather than an angry battle. After a few knocks, the intruder turns and runs. A short distance away, he resumes feeding. There are no injuries and no spilled blood, but the female's consort is clearly the winner.

AVIAN AMOUR It is early morning on Paradise Plain in the Maasai Mara National Reserve. Atop a tall acacia tree, two saddle-billed storks begin a courtship ritual. The male spreads his wings and raises one leg. They touch beaks, and the female attempts to clasp the male's beak in hers. Spreading their wings while clasping beaks, they slowly circle each other again and again. Finally the male lands gently on the female's back. Crouching, with wings outstretched, the huge birds mate, then fly away together to a nearby glade.

DANCE OF DOMINANCE A small group of greater flamingoes stands in the shallows of Kenya's alkaline Lake Borgoria, in the Great Rift Valley. Straining the silt by holding their beaks upside down in the water, they feed on cyanobacteria. Suddenly one individual, its back feathers erect as porcupine quills, approaches a larger one to challenge its feeding spot. They go head-to-head in a flamingo flamenco, necks writhing in graceful curves. When the larger bird claims victory by decisively elevating its head above the challenger's, the smaller one concedes and returns to mining its own claim in the mud.

Colonies in Space

By Walter R. Tschinkel

As an entomologist interested in how ants live underground, I have long wished I could see into the earth and examine every detail of their nests and tunnels. The next best thing, I decided, would be to use their nests as a mold for casting these complex living spaces in plaster. To begin the process, I pour orthodontic plaster (which is stronger than plaster of paris) down the entrance burrows and let it penetrate into the farthest recesses of a colony's nest. Then follows the long, laborious process of progressive excavation and reassembly of the resulting casts. The finished and assembled model is like a positive print of a photographic negative, a record of the art that ants have practiced for millions of years. Collectively the diminutive insects create a giant structure, one sand grain or bit of earth at a time—the product of evolved behavioral programs within each tiny worker's brain.

Nest size varies enormously from species to species. Eastern woodlands *Aphaenogaster* ants make twenty-inch-deep nests occupied by a few hundred workers. New World tropical leafcutter ants create colossal underground metropolises, each housing several million workers that tend huge fungus gardens. Every ant species constructs a nest so distinctive that an entomologist can usually tell which one created it.

Florida's coastal plains are ideal for studying the ants' subterranean architecture: the deep, homogeneous sand is a congenial medium both for the ants and for the researcher seeking a permanent record of these ant cities. After practicing on examples of modest size, I decided to tackle the abandoned dwelling of a particularly ambitious nest-building species: the Florida harvester ant. The nest (pictured opposite) contains 135 chambers arranged along four vertical connecting tunnels that total thirty feet in length. Some of the chambers are specialized for food storage; this nest held about a quarter of a million seeds collected by workers for later consumption. The colony that had built and occupied this nest began with a queen that left her home and mated with another colony's male. After digging a narrow, twelve-inch-deep chamber, she sealed herself inside, laid her first few dozen eggs (a single mating provides the queen with a lifetime supply of sperm), and then reared the hatched larvae and pupae with nutrients stored in her body. These pupae emerged as workers, which then reared more workers, and as the colony grew, the ants deepened the nest and added more chambers. A large harvester ant nest may be as deep as ten feet and contain as many as 200 chambers.

Once or twice a year, the colony abandons its home and excavates a new one—a formidable task that in the case of the nest shown here was completed in four or five days by about 5,000 workers. Together they weighed a total of seven-tenths of an ounce and moved forty-four pounds of sand. Within such nests, the living inhabitants arrange themselves more or less according to their stage of life. Larvae and pupae live in the bottom third, where they grow into young adult workers that will care for the brood of eggs and larvae surrounding them. As the workers grow older, they gradually drift upward, changing their occupation from brood care to more general duties, such as transporting seeds and maintaining the food-storage chambers. Later they take up residence near the surface, where they become the colony's defenders and spend the last quarter of their one-to-two-year lives venturing outside to forage for seeds and insects.

In spring the colony breeds some winged males and unmated queens that will, in time, seek mates outside the colony. During their age-related upward migration, the workers become more and more active in excavating chambers to hold the growing population and its food supply, which is why the nest has a top-heavy shape. The ants' social organization helps shape the space in which they live, and the space in turn organizes the colony by providing separate areas and chambers for various activities and functions. Harvester ant colonies thus have four dimensions—the usual three dimensions of space and the vertical dimension of worker age. □

About 5,000 tiny worker ants excavated forty-four pounds of sand in five days.

The author stands next to his 8.5-foot-tall plaster cast of a Florida harvester ant colony's nest.

Other Stars Than Ours

Aztec astronomers had their own reasons for sky watching.

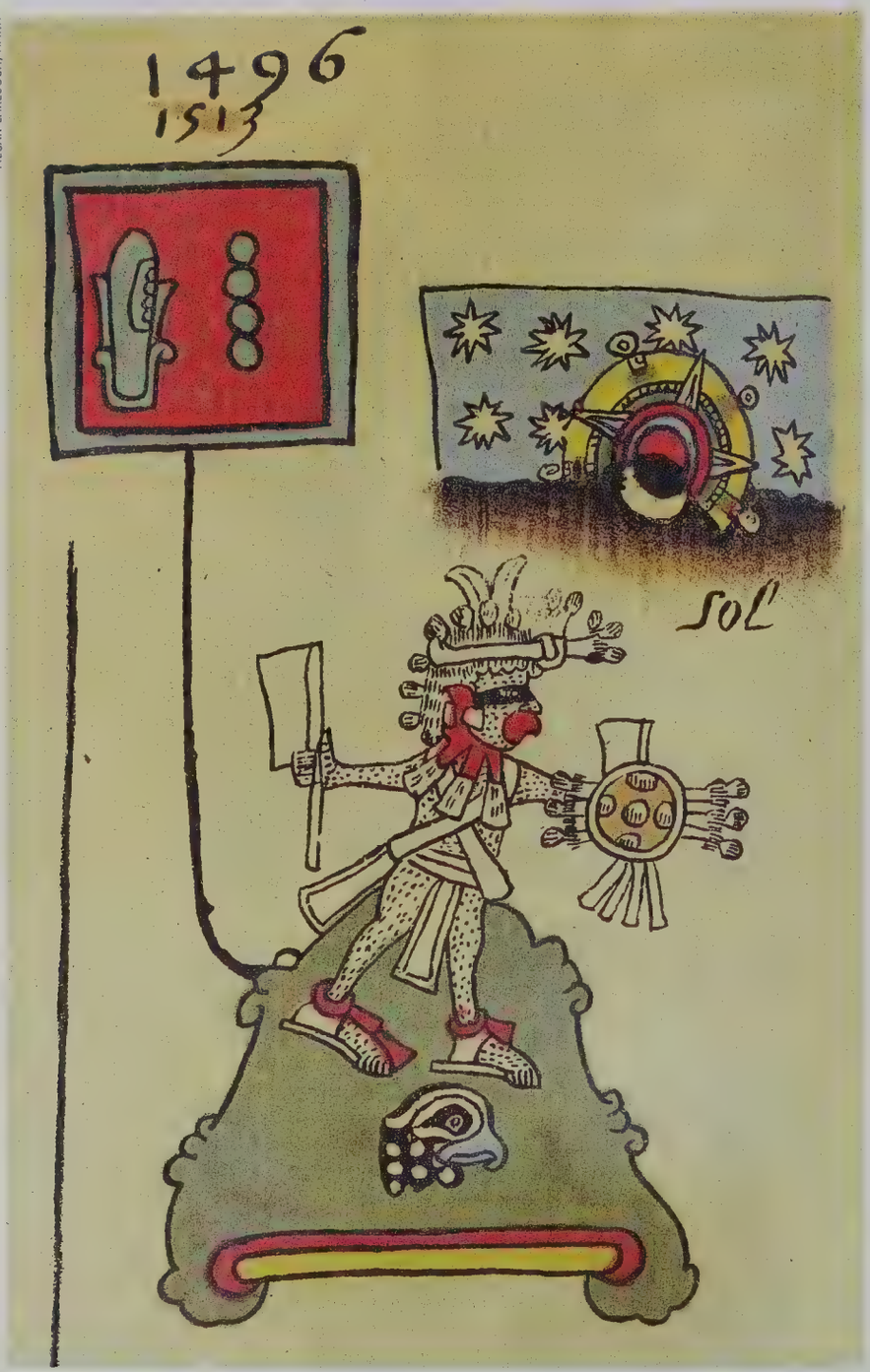
By Anthony F. Aveni

The Aztecs saw in the heavens the sustainers of life—the gods they sought to repay, with the blood of sacrifice, for bringing favorable rains, for keeping the earth from quaking, for spurring them on in battle. Among the gods was Black Tezcatlipoca, who ruled the night from his abode in the north, with its wheel (the Big Dipper). He presided over the cosmic ball court (Gemini) where the gods played a game to set the fate of humankind. He lit the fire sticks (Orion's belt) that brought warmth to the hearth. And at the end of every fifty-two-year calendrical cycle, Black Tezcatlipoca timed the rattlesnake's tail (the Pleiades) so that it passed overhead at midnight—a guarantee that the world would not come to an end but that humanity would be granted another epoch of life. The priests in Tenochtitlan, the Aztec capital, climbed to the top of their sky watchers' temple on the Hill of the Star to witness this auspicious sign. The Aztecs lived their sky, knowing that everything that happened on earth was the outcome of destiny. And they wrote it all down in their books.

Created in the late fifteenth century, the Codex Borgia, a seventy-six-page "screenfold" document of deerskin, is one of a handful of Aztec manuscripts that escaped the Spaniards' book burnings. "Paganism must be torn up by the roots from the hearts of these frail people!" wrote the Dominican friar Diego

REPRINTED FROM *THE CODEX BORGIA: A FULL-COLOR RESTORATION*, BY GISELE DÍAZ AND ALAN RODGERS. CRAIG CHESEK: AMNH.

Five images of Tlaloc, the god of rain and fertility, dominate the twenty-eighth page of an Aztec almanac known as the Codex Borgia. The old woman below Tlaloc in each panel personifies the maize crop, while the dots and icons along the bottom specify dates for the performance of rituals.



MEGAN CARLOUGH; AMNH

The total or near-total solar eclipse of August 8, 1496, is illustrated (upper right) in the early colonial Codex Telleriano-Remensis. The setting Sun is drawn as a crescent, very much as it may have appeared.

Durán, a sixteenth-century chronicler horrified by such documents, which often included graphic depictions of sacrifice and dismemberment. And in fact, some pages in the Codex Borgia do have illustrations of stabbing and blinding and of blood squirting from a torso with dangling intestines. But this random survivor from Mexico's past is also a mine of impressive information about Aztec astronomy.

Much of the first half of the codex prescribes the performance of "debt payment" rituals, as the sixteenth-century Franciscan priest Bernardino de Sahagún put it. These rituals were to be carried out with reference to a sacred calendar called the *tonalpohualli,* the "count of days." This round of time operated much like the Western calendar's cycling of seven named weekdays in tandem with each month's numbered days (Monday the 1st, Tuesday the 2nd, and so on), except that it cycled twenty signs (representing various animals, plants, and forces of nature) against thirteen numbers. This yielded a sequence of 260 uniquely named days (1 Crocodile, 2 Wind, 3 House, and so on), after which the sequence would begin again. The rest of the Codex Borgia is a pictorial narrative detailing the attributes of supernatural characters—probably patron gods of the ruling Aztec lineage for which the codex was prepared—and the world they inhabited prior to humanity's existence.

Recently I have been delving into certain pages in this little-understood codex—pages that resem-

One of the brightest objects in the night sky, Venus commanded the attention of ancient sky watchers, just as it does today.

ble Mayan almanacs, which are well known for their precise prediction of astronomical events. My working hypothesis has been that the dates designated in the Codex Borgia for the performance of rituals were chosen by Aztec prognosticators, who calculated when the heavenly bodies would be in especially auspicious or dangerous positions. If we take just one page in the codex—page 28—as an example, we can begin to see how they put their astronomical expertise to use.

This page (reproduced at the opening of this article) depicts five similar figures, one for each of the cardinal directions (most likely starting with east at the lower right and running counterclockwise to north, west, and south), along with a central one representing the up-down axis, a standard dimension in Mesoamerican cosmology. The featured player is Tlaloc, the goggle-eyed, long-fanged god of rain and fertility, who appears at the top of each frame in a similar pose but with varied accoutrements. At lower right, for example, the rain he unleashes from each hand is studded with flint knives (hail); at upper right, it carries flowers; at lower left, it is accompanied by wind in the form of Quetzalcoatl, the Feathered Serpent. Absorbing the seasonal punishments and rewards doled out by the

forces of nature is the maize crop. In each frame, the maize is personified as an aged female deity, who is shown in a field beneath Tlaloc, flanked by plants bearing ears of corn.

Tlaloc may be the star of the show in another way, because he has a link with Venus. A variety of recent studies of both Mayan and Aztec sculpture, carved inscriptions, and architecture have led to the discovery of a cult known to scholars as the Tlaloc-Venus-War complex, so called because of the imagery worn by its practitioners and the timing of its rites to coincide with particular stations of the planet Venus.

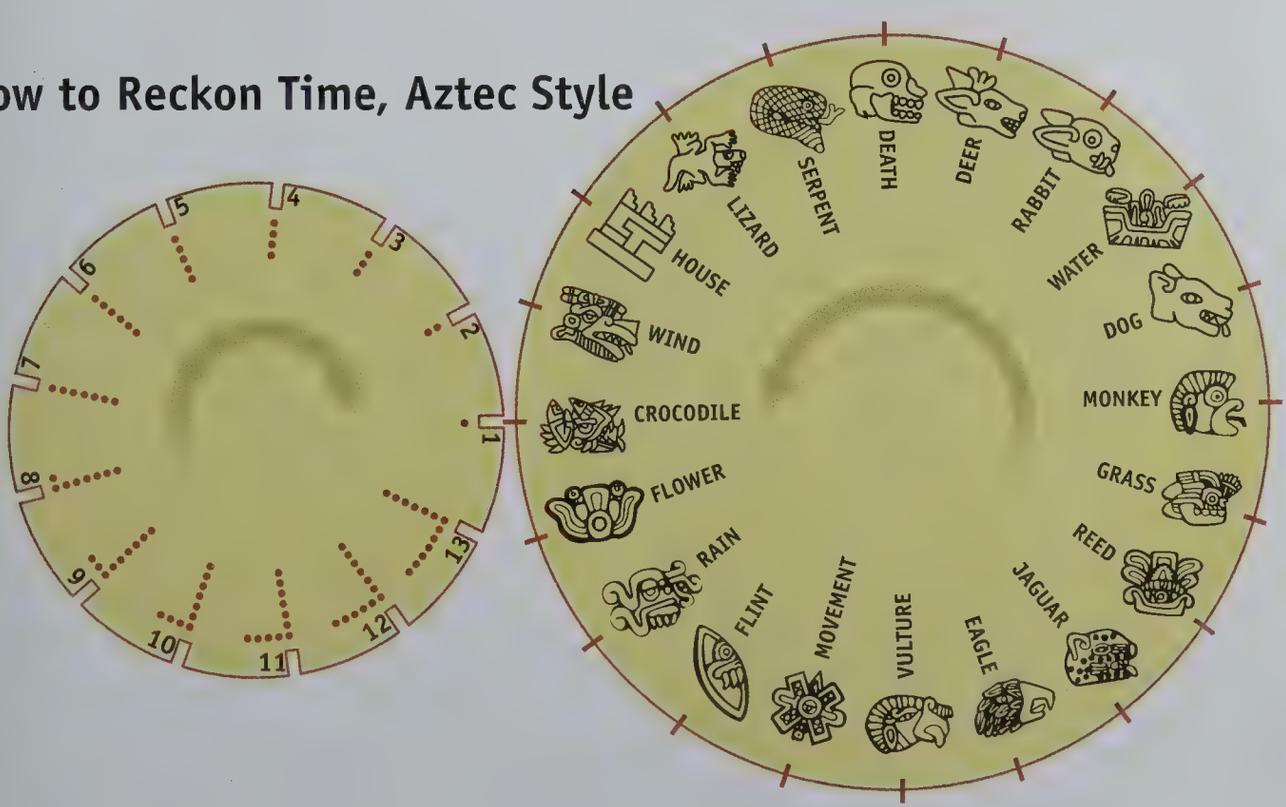
One of the brightest objects in the night sky, Venus commanded the attention of ancient sky watchers, just as it does today. Part of its fascination is that it periodically shifts from appearing as an evening star that sets shortly after sunset to appearing as a morning star that rises just before dawn. Between these manifestations, it disappears from the night sky altogether. All this is a consequence of the fact that the planet's orbit is closer to the Sun than ours is, so that from our point of view Venus seems to move back and forth across the Sun's position. (The reason we sometimes can't see Venus is that it gets so "close" to the Sun that it is lost in the daylight.)

Venus completes its entire appearing-disappearing-reappearing-disappearing act every 583.92 days. Coincidentally, Venus runs through five such cycles in the course of almost exactly eight solar years (a solar year is 365.2422 days). As a consequence, whatever we see Venus doing in the sky on a given date in our calendar, we can expect to see the planet do again, eight years later, on exactly or almost exactly the same day of the same month. For example, Venus begins to appear as a morning star around April 1, 2001, and around April 1, 2009, it will put on a repeat performance. The Aztecs, who had a 365-day calendar by which they measured the solar year, were well aware of this mathematical meshing, which added to Venus's attraction as an astronomical phenomenon.

At the turn of the twentieth century, the visionary German scholar Eduard Seler, who drew on his knowledge of Babylonian astronomical texts, suggested that page 28 in the Codex Borgia may have referred to events in the Venus cycle. He declared himself unable, however, "to discover a law for the days." He was referring to the dates, some of them effaced, that were written along the base of each of the five framed Tlalocs. Fortunately, not only has decipherment of these symbols improved since Seler's time, but high-speed computers now enable us to easily calculate the astronomical events to which ancient dates may correspond.

Within each frame, two *tonalpohualli* (ritual calendar) days are specified, as well as a third day that

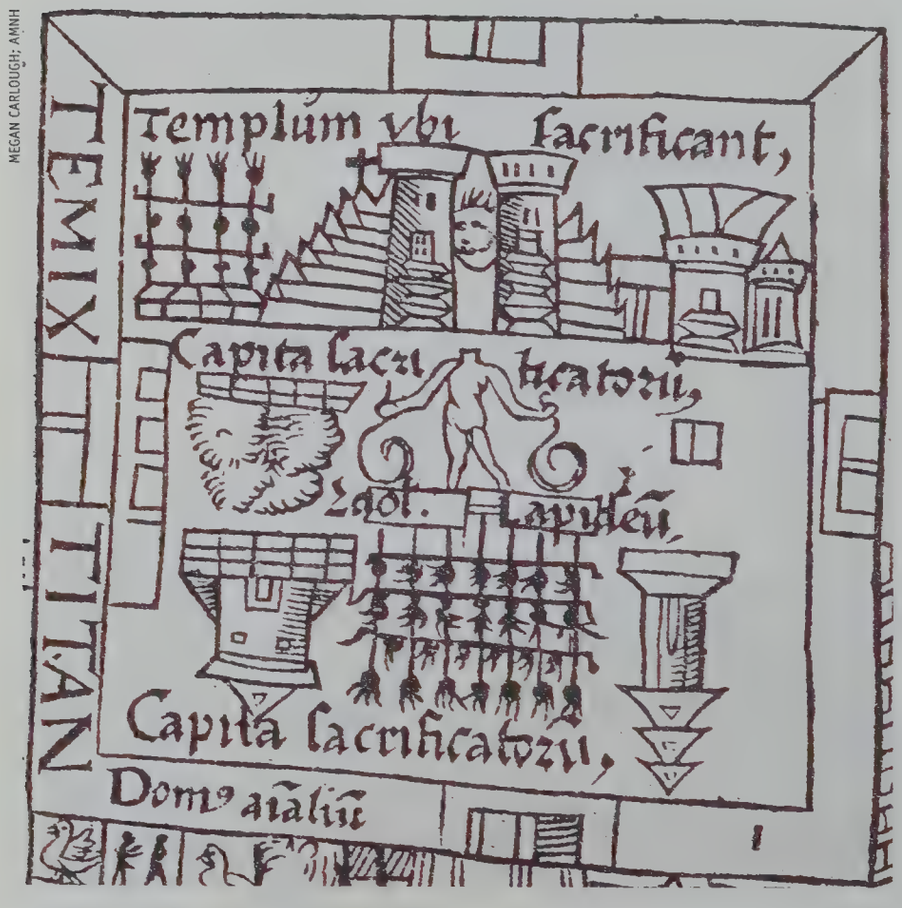
How to Reckon Time, Aztec Style



JOYCE PENDOLA

The Aztec ritual calendar consisted of 260 days, each uniquely named by combining a number (from 1 through 13) with one of twenty signs that represented animals or other natural phenomena. The full sequence can be generated by rotating the numbers and signs in the order shown, beginning with 1 Crocodile.

Right: By combining the 260 named days of their ritual calendar with a 365-day solar year calendar, the Aztecs generated a cycle of dates that did not repeat for fifty-two years. Below: A detail of an early-fifteenth-century map shows the



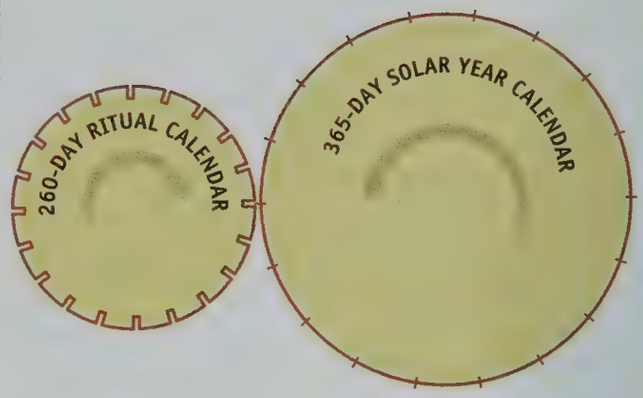
MEGAN CARLOUGH; AMNH

Great Pyramid in Tenochtitlan, the Aztec capital city. The Sun is rising between the pyramid's twin temples—an event that marked the spring equinox.

identifies the particular 365-day year in which the two days fall. Inconveniently for us, however, central Mexican calendars provided no long-term running count for the years, as their Classic Mayan counterparts did. Instead they tell us only the sign and number for the 360th day of the year they are referring to. (It's as if we identified 2001 only as "the year Tuesday-the-25th" because in 2001, Christmas falls on a Tuesday.) But this shorthand presented no problem to the Aztecs, since the same *tonalpohualli* day did not coincide again with the 360th day of the year for a long while.

Indeed, exactly how long did it take for a year name to be repeated? One might guess 260 years, since there are that many distinct days in the *tonalpohualli* cycle, with its twenty day signs and thirteen numbers. But when the twenty day signs are rotated in order against 365-day solar years, only four signs happen to fall on the 360th day—Reed, Flint, House, and Rabbit, after which we come back to Reed. These four, cycled against the thirteen numbers, provide fifty-two unique names for years. Thus the year name in which a person was born would not recur before he or she reached the age of fifty-two.

In each frame on page 28 of the codex, one of the day names serves to refer to the year. We can



JOYCE PENDOLA

distinguish it because the day sign is superimposed over a sort of trapezoidal symbol, which essentially translates as "this is the year." Deciphering the year names on this page, we get the following: upper right, 2 Flint; upper left, 3 House; center, 5 Reed. Although the year names for the bottom two Tlaloc figures are partly effaced, it's a good guess that we're dealing with a sequence of five consecutive years, beginning at the lower right panel, continuing counterclockwise, and ending at the center: 1 Reed, 2 Flint, 3 House, 4 Rabbit, 5 Reed.

Next we have to determine when this five-year sequence falls with respect to our own calendar. From its style alone, we can date the Codex Borgia to sometime between the mid-fifteenth and early sixteenth centuries. Thanks to documents concerning the Spaniards' siege of Tenochtitlan, we know that April 8, 1519, was the first day of an Aztec year and that the name of the year was 1 Reed. This matches the first year in our sequence, so conceivably we are looking at a five-year sequence that ran from April 1519 to April 1524. Or we could drop back one cycle, to March 26, 1467, when 1 Reed also gave its name to a year. Given the approximate dating based on the codex's style, we don't have to look any earlier or later than these two possibilities.

Using computers, modern astronomers can quickly calculate celestial events that were visible in specific places on particular dates.

Taking the years and the day names provided for each year, we can identify specific corresponding dates in the Western calendar. Now comes the fun

part: testing whether the creators of page 28 intended its colorful scenes to be connected with specific, observable celestial events. Checking for any significant astronomical events that would have fallen on or near the dates in question, I found that the earlier sequence (from late March 1467 to late March 1472) yielded the most candidates. Many of its celestial events involve Venus in some way, such as the planet's first appearance as an evening star or its alignment with other planets visible to the naked eye. Still, not every date provides a perfect match. Those that don't may have referred to celestial observations that the Aztecs deemed more important than we do and that may become apparent to us once we learn more. The Aztecs may even have sought to predict certain meteorological or geological phenomena—earthquakes, volcanic eruptions, hailstorms, or the rare snowfall—that we do not include in the category of astronomical event.

Page 28 of the Codex Borgia is, in effect, one page in an almanac produced by astronomer-calculators to suit a particular time and place of celestial observation. (The adjoining page 27 seems to be a master plan that embraces larger segments of time, suggesting that the almanac as a whole may cover a full fifty-two-year period, from 1467 to 1519.) Each of the dates on page 28 was apparently considered a prime time to schedule a suitable propitiation ritual to Tlaloc, the deity that dominates the images. An important purpose of such rituals seems to have been to bring on needed seasonal rains or to ward off calamities that could befall the maize crop. Four of the dates cluster around mid-May, when the rains begin, a crucial time in the agricultural cycle.

Given the connectedness, for the Aztecs, of fertility, warfare, and Venus, the meaning of this page may run much deeper. The rain-drought cycle in the biosphere, the cycle of kingship in the human sphere, and the periodic motions in the celestial sphere all undergo similar junctures: just as new maize germinates, so does the empire flourish in the presence of the newly "sprouted" ruler, whose conquest and acquisition of tributary states are

On June 6, 1468, sky watchers in Tenochtitlan would have witnessed an alignment of planets and the setting Sun, close to a constellation they called the ball court (Gemini). Aztec astronomers apparently foresaw this event, whose date is listed on page 28 of the Codex Borgia: the year 2 Flint, the day 10 Rain.

RON MILLER; HIEROGLYPHS REPRINTED FROM *THE CODEX BORGIA: A FULL-COLOR RESTORATION*, BY GISELE DÍAZ AND ALAN RODGERS

sanctioned in heaven by the wandering of his patron star. These interconnections aren't really that exotic. We should not forget that Western astronomy before the Enlightenment was also driven largely by astrological and religious concerns (even the major Christian holidays were pegged to observable celestial events). Louis XIV proclaimed himself Sun King; more recently, an astrologer was thought to have played a role in Ronald Reagan's conduct of presidential affairs.

Ancient and indigenous peoples created elegant systems for making things comprehensible—not to us but to themselves.

While the Maya have long been credited with prowess in calendrical and astronomical matters, we are now seeing that the upstart Aztecs were also sophisticated in these realms. In fact, it appears that Mesoamerican cultures were much more interrelated than we once thought. The connections extended to their pantheons of gods, with those of the Maya and the Aztecs, like those of the Greeks and Romans, displaying many correspondences.

But perhaps the most important lesson we can derive from the study of Aztec astronomy is that these people simply were not concerned with what seems important to us now. Even the eclipses of the Sun they chose for temporal markers had to fall on special days of the *tonalpohualli;* whether or not these eclipses were spectacular by our criteria mattered less. But these astronomers were precise. For example, if we look at the early- to mid-sixteenth-century manuscript known as the Codex Telleriano-Remensis, we find that an eclipse that took place on the afternoon of August 8, 1496, is depicted just about as it happened, with the still partially eclipsed solar disk plunging into the mountainous horizon west of Tenochtitlan.

Caught up in the theory of progress, we tend to focus on whatever glimmers of modern science we find in ancient or indigenous ways of understanding nature. We see that a certain group discovered an herb containing a curative chemical or recorded the position of the rising Sun at the vernal equinox. And then we lament, Just think what they might have accomplished if they had taken the "right track" and pursued this knowledge more single-mindedly. But we would do better to study how and why these cultures built elegant systems for making the things they observed comprehensible—not to us but to themselves. Other peoples' motives for sky watching may tax our patience and require dredging up subjects that suit neither our tastes nor our prejudices. But our failure to understand these motives will always be our loss. □

Tenochtitlan is recreated in a mural, below, painted by Diego Rivera in 1945 for the National Palace in Mexico City. Opposite page: A mask representing the god Xolotl, possibly associated with the planet Venus as evening star.

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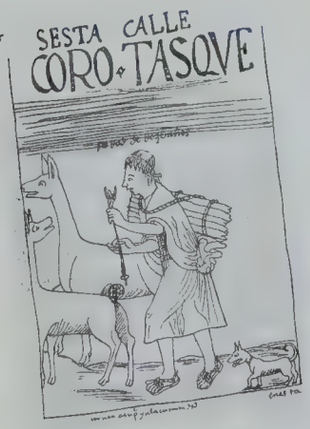


WORKING GIRL

For many young girls in Andean Ecuador, life involves labor. For Rosa, the tradition continues—with some adjustments.

Story by Lynn A. Meisch ~ Photographs by Ligia Botero

Above: As a seven-year-old, Rosa made breakfast for her family. Top of page: A drawing from a seventeenth-century volume by Felipe Guaman Poma de Ayala portrays the work expected of a teenage girl during Inca rule.

Rosa was another blessing and another pair of hands when she was born in 1988. Her home was an adobe-and-thatch structure with an attached cooking shed, set on a slope of Taita (Father) Chimborazo, the 20,702-foot snowcapped Andean volcano that dominates Ecuador's Chimborazo Province. Like most of the families living in small mountainside communities nearby, hers scratched a living from *allpa mama* (mother earth) through hard agricultural labor and the sale of surplus barley and potatoes at the weekly market in Riobamba, about fifteen miles away.

By the time Rosa turned five, she was rising at five A.M. to cook and clean for herself, her mother, and two younger brothers. After school she washed clothes; helped her mother plant, weed, and harvest potatoes and other crops; and found time to do homework and to play. She also cared for her youngest brother (the other was making himself useful in the fields). Within a few years, however, Rosa's life, although still governed by the tradition that

young indigenous girls are expected to work and help their families, veered from its expected path.

In the Ecuadorean Andes, I have watched a four-year-old girl weed the garden with a baby sibling strapped to her back and I have held my breath as a two-year-old boy carried a knife across the room to his father. Children in these communities are given many responsibilities at an early age, and parents are confident in their sons' and daughters' ability to carry out what are, to us outsiders, dangerous and difficult tasks. Every family member is valuable. "Children bring joy," I've been told. They also contribute to the maintenance of the household.

The Andean concept of childhood as being useful and productive is not of recent origin. When the Inca conquered Ecuador in the fifteenth century, they introduced the Quechua language (which Rosa speaks at home) and imposed a tax system in which payments were made in human labor. *The First New Chronicle and Good Government,* a 1,200-page manuscript written and illustrated by the Andean writer Felipe Guaman Poma de Ayala, portrays life in the Inca empire before and after the

After school, Rosa helped her mother in the potato fields, washed clothes, and took care of her youngest brother.

Most rural schools are poorly equipped. Right: At Rosa's school, each child brought wood for the lunchtime cooking fire. (Rosa is second from left.)

Spanish conquest. Completed in about 1615, the book includes a description of the Inca's division of both males and females into ten categories, based on the capacity for work. Adults in the prime of life were the most important group, not only for reproduction but also for their labor. Adults might spin and weave for the state, maintain roads and bridges, or farm the lands set aside for the benefit of Inca rulers. Some adult males left home to serve in the Inca army or to work on construction projects for a specified time.

According to Inca dictates, girls between the ages of twelve and eighteen—called "short-haired girls"—owed help in many forms to their parents and communities. They were expected to spin and weave, pasture llamas and alpacas, work in the fields, gather firewood, make *chicha* (corn beer), cook, and clean the house. One of Guaman Poma's drawings shows a teenager carrying out three tasks at once: with a load of firewood strapped to her back, she spins while herding llamas (see page 74).

Girls between nine and eleven were called "girls who gather flowers" because they collected flowers and plants for dyeing yarn and also picked edible herbs and plants. They were assigned these tasks, Guaman Poma observed, "so they would not be lazy." Indeed, the Inca's three commandments were "Don't steal, don't lie, don't be lazy"—admonitions repeated in indigenous communities today.

The eighth category consisted of girls between five and nine. These children were called "girls who go about playing," perhaps a misnomer from our point of view, given how much work they did. According to Guaman Poma, "They served their mothers and fathers by bringing firewood and straw for thatching. They began to work, spinning delicate yarn, and collecting aquatic plants, and they helped make *chicha*, care for younger children, and carry infants on their backs." Rosa's early childhood resembled the Andean model in many respects, especially in terms of the amount and kinds of labor she did for her family and the reciprocal relationships of work and caring.

High school was not an option for Rosa. At the age of eleven, she became a maid's assistant in the city of Riobamba.

Anthropologists and historians have long noted that reciprocity, both between humans and between humans and supernatural beings, lies at the core of Andean values. Each summer when I arrive in Ecuador to conduct research, I bring gifts of clothing for my godchildren; they and their parents greet me with gifts of food. During Inca times, humans made offerings to the earth in return for a good harvest. Such offerings are still called "paying the

earth." In exchange for their labor tax, communities received food from Inca storehouses in times of famine, and indigenous families whose adult males were away working or fighting for the Inca state were fed at public expense.

Following the Spanish conquest of the Andes, the equation became unbalanced. In 1532 the king of Spain gave Spanish overlords the right to collect labor and tribute from native Andeans in return for Christianizing them, but the Spaniards' obligations did not include feeding the families of those working in Spanish mines, sweatshops, and haciendas (large farms and ranches). Indigenous people in Chimborazo who were unable to meet their tribute or whose land was expropriated eventually became tied to the region's haciendas in a system of debt servitude that lasted until an agrarian reform in 1964.

A quarter of a century later, only 25 percent of Ecuador's adults were employed full-time, and few of these shared Rosa's ethnic and class background. Rural community schools, where Quechua-speaking children are often taught by Spanish-speaking outsiders, generally impart little more than minimal numeracy and literacy. Because the government provides only the building and the teachers' tiny salaries, while parents must pay for books, school supplies, and uniforms, even primary schooling is out of reach for many families. High school was not an option for Rosa. In any event, she didn't like school.

If Rosa had followed the traditional rural pattern, she would eventually have married a young man from her own or a neighboring community and started a family. But Rosa's life took another direction. With the area where she was raised becoming increasingly impoverished, her mother sent her to work in the city; domestic service has long provided cash employment for some rural girls. In 1999, at the age of eleven, Rosa became a maid's assistant in Riobamba, the largest city in the province.

During the 1990s, a decade plagued by political, economic, and natural disasters, the trickle of people of all ages from the Ecuadorean countryside into the cities became a torrent. Hundreds of thousands of adults left home to look for work in large cities and abroad; tens of thousands of young people like

In 1999 Rosa's family, including her grandmother (second from left) and mother (far right), traveled to Riobamba for her first communion, then took Rosa home for a visit.

Rosa in Riobamba: She has few friends her own age and rarely leaves the house unchaperoned.

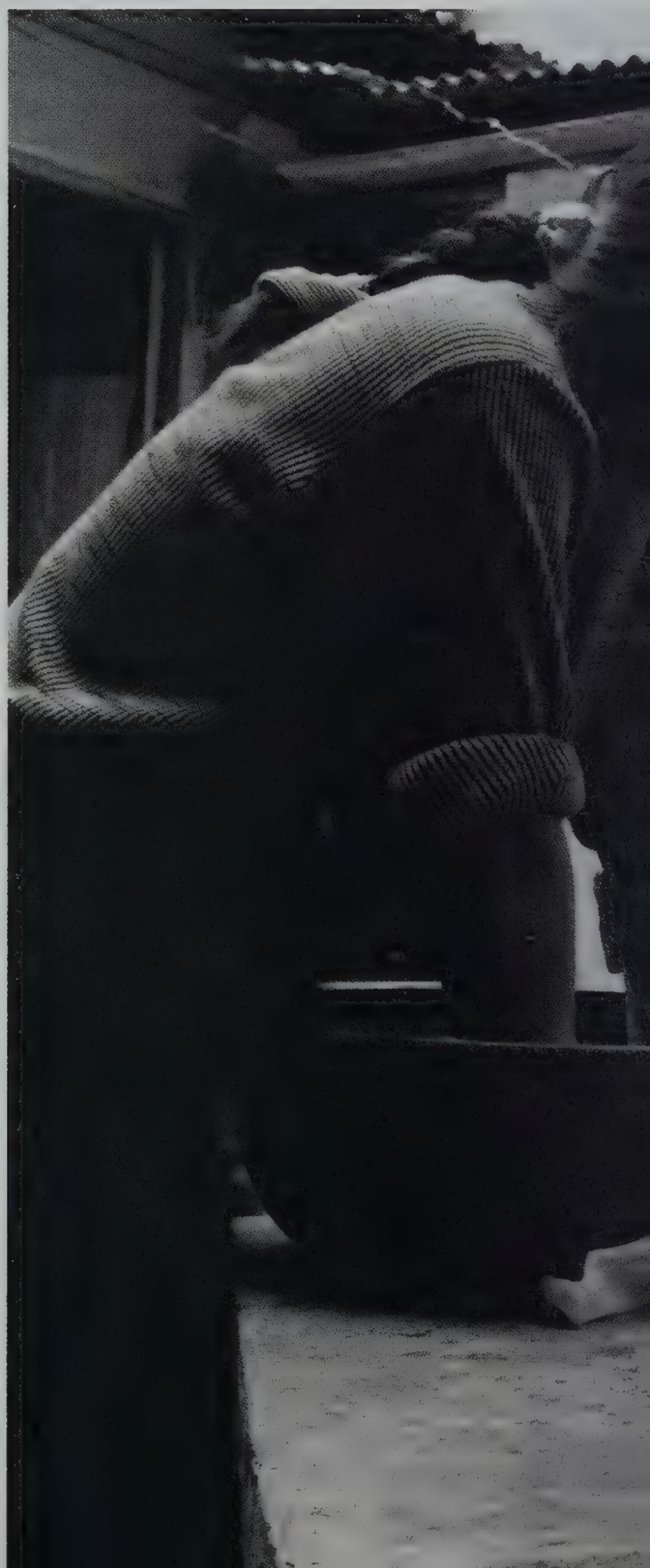
Rosa, children really, also migrated to find work. According to Ecuador's National Migration Service, of the country's 12.4 million people, 300,000 emigrated in just the last few months of 1999—many of them illegally. The United States, Italy, and Spain were—and still are—favorite destinations. A *coyote* (smuggler) charges between $5,000 and $10,000 to conduct emigrants on the dangerous overland journey to the United States. Many emigrants leave their children in Ecuador because of

From the pittance she earns, Rosa sends money home to her mother and saves some for herself.

the dangers of the journey. Most do not contemplate a return home until their debt is paid off and some money put aside. Successful migrants work for several years to pay off the debt, then save money to buy a taxicab or start a business if and when they return home, all the while sending remittances to their families. (The pattern of emigration and absentee parenting is so prevalent in Ecuador that the newspaper *Hoy* ran an article this past August on the psychological trauma suffered by children whose parents are abroad.)

In Riobamba, Rosa ended up helping an elderly woman, Mama Cata, to care for the two children of a couple who emigrated to New York City in 1992. These children, now about thirteen and fifteen, barely remember their parents. Mama Cata also has charge of the little girl her own daughter left behind when she emigrated to Spain.

Rosa helps Mama Cata cook, clean, wash clothes by hand, and do other household chores.



She also takes care of Mama Cata's granddaughter. Like the "short-haired girls" of Inca times, Rosa is accomplished and efficient in all the domestic arts. Typically, someone in her position is lucky to earn a dollar a day plus room and board for six and a half to seven days' labor, but *"algo es algo"* ("something is something"). From the pittance she earns, Rosa sends money home to her mother and saves some for herself.

Mama Cata is fond of Rosa, watches her carefully, and sees to her religious education. In 1999, in preparation for her first communion, Rosa attended catechism lessons in the afternoon; it was her only chance to go out unchaperoned. Rosa has no friends her own age and no opportunities to make them. But she hasn't been abandoned by her family. For her first communion, her mother and grandmother, along with some older siblings and other relatives, made the trip to Riobamba. Afterward, Rosa went home with them to the slopes of Taita Chimborazo to celebrate. She had grown so big that her cousins barely recognized her. □

Rosa assists with the household chores. She also takes care of Mama Cata's granddaughter.

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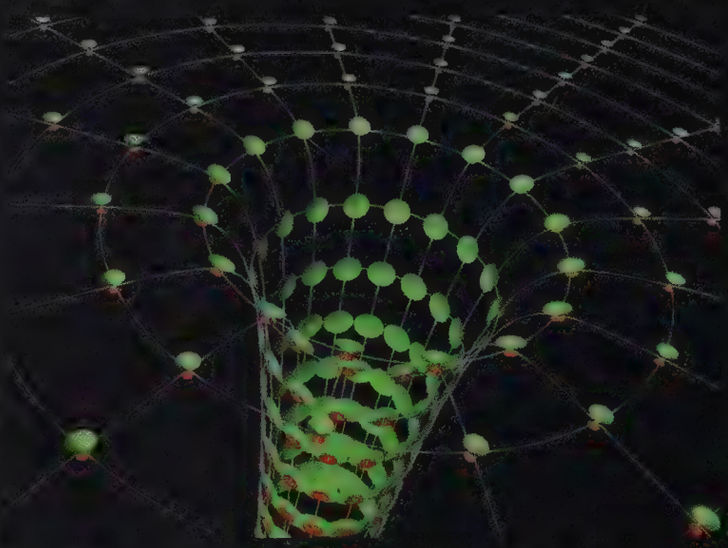

The gravitational forces in a Schwarzschild black hole are so strong that anything within its radius—even light—cannot escape. (The colored cones represent how light would respond to the intense gravity.)

Plenty of Nothing

And nothing is plenty for some sky watchers.

By Richard Panek

Devoting a column that's supposed to be about what you can see in the night sky to something you can't see may seem to make no sense. But then, there's a lot about black holes that seems to make no sense—at first.

Although we tend to think of black holes as a purely post-Einsteinian conception, the credit for coming up with the idea belongs to eighteenth-century British geologist and astronomer John Michell, who used Newton's laws to deduce the possibility of what he called a "dark star"—a mass so substantial that not even light can escape its gravitational field. The idea first received widespread attention in French mathematician and astronomer Pierre-Simon de Laplace's wildly popular 1796 book *Exposition du système du monde*. But such speculation didn't begin to assume modern form until 1916, when the German astronomer Karl Schwarzschild seized upon the brand-new notion of relativity to produce his landmark paper "On the Gravitational Field of a Point Mass According to the Einsteinian Theory."

There the matter (or disappearance thereof) rested for the next half century: mathematically possible, even speculatively irresistible, but *real*? In 1967 U.S. physicist John Archibald Wheeler dubbed any such objects (should they exist) black holes, and throughout the 1960s and 1970s theorists worked out models for how these objects might reveal themselves. Since a black hole, by definition, emits no electromagnetic radiation, the only way to find one would be indirectly. This could be done by observing a signature gravitational effect on nearby visible objects or by monitoring through X-ray telescopes the "death scream" of gas that's been heated to millions of degrees as it plunges toward the event horizon—the black hole's ring of no return.

Still, observers remained understandably reluctant to come right out and say that something like Cygnus X-1—a binary star system consisting of one visible star rapidly orbiting one invisible companion that is radiating extraordinary levels of X rays—contained a black hole. As one astronomer said at a press conference on black holes just last summer, "It's taken us this long to convince ourselves they're real."

Not until May 6, 1994, did astronomers identify a black hole with relative certainty. It resided, they said, at the heart of M87, an elliptical galaxy 50 million light-years from Earth and previously best known for an unusual jet emanating from it, the first such extragalactic jet discovered (by American astronomer Heber Curtis in 1918). What convinced them of the existence of a black hole within M87 was the Hubble Space Telescope's detection of gas whipping around the core of the galaxy at 1.1 million miles per hour—meaning, according to their calculations, that whatever was driving this frenzy had to have a mass equivalent to 3 billion Suns. What's more, the mysterious jet, extending a distance of at least 5,000 light-years outside the galaxy, was probably fueled by that mass at M87's center. In the seven years since then, so many black holes have been detected that one astronomer, with only a little irony, has described identifying one as "even mundane."

Astronomers today no longer ask whether individual specimens might exist but how best to think about black holes collectively. A supermassive black hole—one with a mass equaling between 1 million and 3 billion Suns—may perhaps reside at

the center of every large galaxy (including our own Milky Way, as observers demonstrated in 1998). Stellar-remnant black holes—those with a mass between three and thirty Suns—might number as many as 100 million per galaxy, including one situated only 1,600 light-years from Earth, as astronomers announced just last year. Stellar-remnant black holes are formed by the collapse of massive stars; as for supermassive black holes, nobody knows where they come from or why they seem to have a mass directly proportional to the size of their host galaxy.

But at least astronomers at long last are beginning to figure out what to ask about black holes, besides the obvious question of what happens to anything that goes into one (see "Universe," October 1995). So what's in all this for a sky watcher? Nothing, at least in terms of something to see. But in terms of something to think about—just as much the point for many amateurs studying the night sky—the answer is, Plenty. If the galaxies in the universe number 125 billion (according to the latest estimates, which are always subject to upward revision), and even if stellar-remnant black holes number "only" 50 million per galaxy, that would bring the universe's black hole population to well over 5 quintillion.

You can use binoculars or a telescope to find M87 in the Virgo cluster of galaxies, on the border between the Virgo and Coma Berenices constellations, which this month will be high in the southeastern sky after nightfall. And if, while you're staring up at the heavens, some neighborhood wit should ask the inevitable "What's up?" you can answer, "Nothing"—and then go on to explain just how much of it there is.

Richard Panek is the author of Seeing and Believing: How the Telescope Opened Our Eyes and Minds to the Heavens *(Penguin, 1999).*

THE SKY IN APRIL

By Joe Rao

Mercury is out of sight almost all month, reaching superior conjunction (and slipping behind the Sun) on April 23. But this quick little planet reappears a week later, just above the northwestern horizon at dusk.

Venus has a busy and interesting month. The brilliant planet was visible both after sunset and before sunrise for a few days beginning March 29, but for most of April, Venus becomes purely a planet of the dawn. It rises about thirty-five minutes before the Sun on the 1st, as seen from 40° north latitude, and by month's end it appears about one and a half hours before sunrise. Seen through a telescope on April 1, its large, thin crescent is 1/30 the apparent diameter of the full Moon but shrinks by nearly a third as the month progresses.

Mars rises within an hour of midnight local time during April. Due to its rapidly intensifying luminosity (magnitude –0.2 on the 1st, reaching –1.0 by the 30th) and its increasingly noticeable fiery color, it is becoming more prominent. This month Mars finally moves close enough to Earth to give observers a real shot at catching some surface features with at least a medium-sized telescope, plus very good viewing conditions, particularly when the planet is high in the southeastern sky toward dawn. Mars will appear above and to the right of the waning gibbous Moon during the morning hours of April 13.

Jupiter is the first "star" to come out at early dusk this month. Look for it in the western sky. It is soon followed by Sirius in the southwest at a similar altitude above the horizon (Jupiter's magnitude is –2.1; Sirius's is –1.4). As the giant planet nears the end of its yearlong apparition (it sinks into the sunset in May), it edges noticeably away from Saturn. By April 16, Jupiter's eastward motion carries it just over 5° north of the reddish giant star Aldebaran, completing a triple conjunction with this star that began last September. A very thin crescent Moon lies well below Jupiter on the evening of the 25th. The planet sets about three hours after twilight's end on April 1 but less than an hour after dusk on the 30th.

Saturn can be found at dusk as a yellowish, zero-magnitude "star" about 30° above the western horizon (the width of your fist held out at arm's length is roughly 10°) and 9° below and to the right of Jupiter at the beginning of April. During this time, the planet sets about three and a half hours after the Sun. But by the end of the month, Saturn stands only about 10° high in the northwestern sky at dusk, setting just ninety minutes after the Sun. A striking array awaits you as darkness falls on the evening of the 25th: the delicate sliver of a two-day-old Moon joins the eye-catching triangle of Jupiter, Saturn, and Aldebaran. Saturn lies several degrees below and to the right of the Moon.

The Moon is at first quarter on April 1 at 6:49 A.M. The full Moon occurs on April 7 at 11:22 P.M., last quarter on April 15 at 11:31 A.M., and the new Moon on April 23 at 11:26 A.M. The Moon returns to first quarter on April 30 at 1:08 P.M.

Unless otherwise noted, all times are given in Eastern Daylight Time.

REVIEW

Short Shrift to Long Life

Living to a very advanced age is unlikely, the authors argue. But are they right?

By Steven N. Austad

FROM *LOVE IN THE 90S: A GRANDDAUGHTER'S PORTRAIT*, BY KERI PICKETT

Although the dangers of basing predictions of the future on short-term statistical trends are well known, they're sometimes conveniently forgotten. Johns Hopkins University biostatistician Raymond Pearl, one of the grand characters of twentieth-century science, spent much of his career examining the growth trajectories of fruit fly and mouse populations to determine whether there was a universal law of mortality—the logistic curve. Logistic population growth proceeds rapidly at first, then gradually slows to a stop as it comes up against a biological limit. Invoking this "law" in the early 1920s, Pearl predicted that the world's population would reach its limit of 2 billion in the year 2026. In fact, it reached the 6 billion mark in 1999.

Similarly, in their book *The Quest for Immortality: Science at the Frontiers of Aging,* demographers S. Jay Olshansky and Bruce A. Carnes cite another statistical law of mortality, the Gompertz function, which states that the chance of dying doubles every seven or so years after puberty. The authors project that maximum human life expectancy (currently between seventy-five and eighty years in the countries with the best health status) will not exceed eighty-five years anytime soon. They also think we should be glad it won't, because society might collapse under the collective expense of supporting the decrepit and demented elderly. To support this view, and to expose the long and continuing history of human folly in the pursuit of immortality, they have written a delightfully accessible, evolutionarily sensible, and often highly personal book on the history of prospects for human longevity.

Some demographers, believing that the Gompertz pattern has no discernible biological underpinnings, vehemently disagree with Olshansky and Carnes and assert that babies born today can expect to live as long as 100 years. Underlying these contending projections are very different visions of biology and the future of humanity. The Carnes-Olshansky vision is that our bodies are like race cars, exquisitely designed to perform well for a certain time but likely to collapse as the parts—engineered to last only so long—give out one by one at an accelerating rate. So many things go wrong late in life that improved success in treating individual problems doesn't affect average survival all that much. Carnes and Olshansky have calculated, for instance, that eliminating all cancers (responsible for about 25 percent of all U.S. deaths) would increase life expectancy by only about three years. In giving as clear an explanation of the relation between evolution and aging as I have ever come across, they assert the necessity of a collective collapse of parts. They also make an excellent case that given the current state of medical technology, the assumptions necessary to project a 100-year life expectancy defy biological rationality.

The Quest for Immortality: Science at the Frontiers of Aging, *by S. Jay Olshansky and Bruce A. Carnes (W. W. Norton, 2001; $25.95)*

But the authors' concentration on the average age at which individuals die can be misleading. Life expectancy anywhere in the world before the past couple of centuries probably never exceeded twenty-five or thirty years. This doesn't mean that an adult was considered elderly at forty or that extreme ages weren't reached—only that infant mortality, which has a disproportionate effect on life expectancy, was very high.

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The ancient Egyptians, for instance, understood old age in terms that are easily recognizable today. One pharaoh, Ramses II, probably lived into his nineties.

Aging is not a modern phenomenon. What is modern is the likelihood of living to a very old age. The probability in the United States of any given person's reaching eighty is now double what it was in 1940, but this means that more people than ever before will be leading lives of chronic disability. What we are now adding to our lives is what these authors call manufactured time—that is, life purchased by medical intervention but not necessarily high-quality life. Yet need it be so?

Prolongevists believe that aging and death can be modified right now. All we need to do is swallow supplements, follow a special dietary plan, inject hormones, use certain relaxation techniques. Such beliefs can be traced back at least to early Taoism, in the third century B.C., and their historical development is nicely documented here. One thing common among antiaging therapies, then and now, is the lack of any evidence that they work. My current favorite in this vein (so to speak) is the injection of human growth hormone, the virtues of which have been promoted by Hollywood celebrities and "medical experts." There does exist firm documentation that this hormone can increase muscle mass and decrease body fat (as do exercise and anabolic steroids). The popularity of such injections is particularly ironic, however, given that convincing evidence has accumulated over the past three to four years that in mice, at least, increased growth-hormone levels lead to a shorter life.

As much fun as it is to debunk so-called antiaging therapies, I think Carnes and Olshansky have allowed their delving into this long history of human silliness to make them unduly pessimistic about the capacity of new medical technologies to increase health and life span in the relatively near future. We have already been able to extend life as much as threefold in experimental animals such as the roundworm *Caenorhabditis elegans*. Nearly every month, researchers find new genetic manipulations and synthetic pharmaceuticals that extend life and health by 30 to 50 percent in fruit flies and mice. The cloning technology developed in mammals over the past few years also holds the promise of using our own cells for growing replacement cells, tissues, and even organs.

Taken together, these findings suggest to me that we will soon be making very real progress toward slowing the aging rate in humans. In fact, I believe this firmly enough to have made a bet with Olshansky on the matter. We each put $150 into a trust fund to be invested for the next 150 years. If at that time (2150), someone has lived to at least the age of 150, my heirs will get the accumulated cash. If not, his heirs will get it. That $300, invested today and returning 10 percent per year (about the stock market average for the past seventy years), will turn into almost $500 million. Compared with that miracle of compounding, the development of medical therapies to slow human aging seems almost child's play.

Steven N. Austad is a professor of zoology at the University of Idaho and the author of Why We Age: What Science Is Discovering About the Body's Journey Through Life *(John Wiley & Sons, 1997).*

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Gigalopolis

By Robert Anderson

I have always enjoyed time-lapse photography—you know, flowers opening, seeds sprouting, clouds racing across the sky as the sun arcs toward the western horizon. By distorting time, these films seem magical, allowing us to see what before we could only imagine. And as a result, we often gain a new understanding. Project Gigalopolis, a joint effort of the University of California at Santa Barbara and the U.S. Geological Survey (www.ncgia.ucsb.edu/projects/gig/ncgia.html) is a prime example. It seeks to document the explosive growth of our cities in recent years. This is an important task, given the project's assertion that "urban settlements and their connectivity will be the dominant driver of global change during the twenty-first century."

To view some of the group's first efforts, click on "Urban Growth Animations." You can see cities and towns in San Francisco's Bay Area gobble up undeveloped land and merge, or you can watch Washington, D.C., spread far beyond the beltway and fuse with Baltimore. For decades, urban growth was slow and had little impact on the surrounding environment. Then suddenly in the 1950s, things began to accelerate—perhaps due to the combination of booming populations, a national campaign of highway building, faster cars, and cheap gasoline. Now cities and their suburbs are poised to consume rural lands that not long ago were considered well beyond their reach.

Project Gigalopolis plans to use its model to predict the expansion of the urban areas around New York City, Chicago-Milwaukee, Philadelphia-Wilmington, Portland-Vancouver, and elsewhere. Those of us who have grown up near any of these cities are well aware of the tremendous growth, but only this sort of time-lapse animation can give us a real sense of what we have lost and what the future may hold.

Robert Anderson is a freelance science writer living in Los Angeles.

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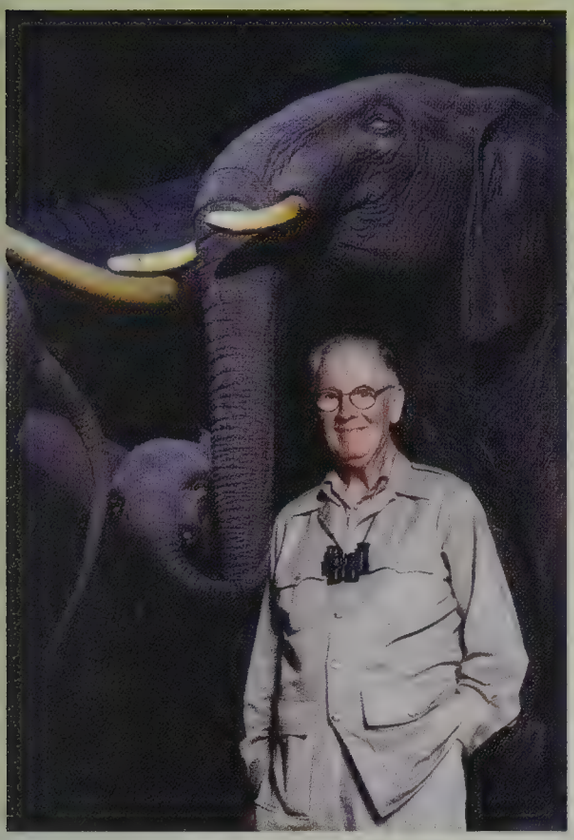

World traveler Everett Hoffman's stories of his adventures are filled with curious children, roving wildlife, sultry afternoons and African dictator's cronies. These days his adventurous spirit has led him to the AMNH and the research expeditions of its scientists to every continent of the globe.

In fact, he is so impressed with this facet of the Museum's mission that he has established the Everett Hoffman Endowed Fund for Research Expeditions. He recently set up this fund with a Charitable Gift Annuity and will supplement it with a future bequest.

A Gift Annuity is a way to support the Museum and provide lifetime income to one or two people. When low-yield stock is used to fund the plan, capital gains tax is avoided.

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BOOKSHELF

The Universe Unveiled: Instruments and Images Through History, *edited by Bruce Stephenson, Marvin Bolt, and Anna Felicity Friedman (Adler Planetarium & Astronomy Museum/Cambridge University Press, 2000; $29.95)*
Since the late fifteenth century, humans have been devising elegant and innovative technologies for measuring and mapping Earth, navigating, keeping time, and observing the heavens.

The Little Ice Age: How Climate Made History 1300–1850, by Brian Fagan *(Basic Books/Perseus, 2001; $26)*
While documenting the rapid climate shift known as the little ice age, archaeologist Fagan traces its effects on history and human experience, from the demise of Viking colonies in Greenland to the Irish potato famine.

The Ghosts of Evolution: Nonsensical Fruit, Missing Partners, and Other Ecological Anachronisms, *by Connie Barlow (Basic Books/Perseus, 2001; $26)*
Barlow examines the idea of "missing partners" in nature, focusing on the many fruits that evolved their adaptive features during millions of years of association with the great mammals that fed on them. Most of these so-called megafauna went extinct 13,000 years ago, leaving the plants behind as anachronistic survivors in today's world.

No Apparent Danger: The True Story of Volcanic Disaster at Galeras and Nevado del Ruiz, *by Victoria Bruce (HarperCollins, 2001; $26)*
Surviving Galeras, *by Stanley Williams and Fen Montaigne (Houghton Mifflin, 2001; $25)*
Linking the disastrous events of two recent eruptions in southern Colombia, Bruce, a science reporter, describes the harrowing ordeal of those who experienced the disasters firsthand and survived. Williams, leader of a volcanological expedition to Galeras during the 1993 blowout, recounts his own close encounter with death. Both stories create a framework for exploring modern volcanology.

Birthplace of the Winds: Storming Alaska's Islands of Fire and Ice, *by Jon Bowermaster (National Geographic Books, 2001; $26)*
Bowermaster writes about a twenty-five-day kayaking expedition in the Aleutians (the island chain off Alaska designated a Biosphere Reserve by UNESCO) and produces an informative account of a largely unknown area, volcanically active and extraordinarily rich in fauna.

From Ellis Island to JFK: New York's Two Great Waves of Immigration, *by Nancy Foner (Yale University Press/Russell Sage Foundation, 2000; $29.95)*
By comparing factors such as race, gender, ties to the home country, and the role of education, anthropologist Foner contrasts New York City's immigrant experience at the beginning of the 1900s with the second influx at century's end. Today's immigrants from the Dominican Republic, Mexico, Jamaica, and China are again changing the face of the city.

On Fertile Ground: A Natural History of Human Reproduction, *by Peter T. Ellison (Harvard University Press, 2001; $27.95)*
As an anthropologist viewing human reproduction from multiple perspectives—anthropology, ecology, and evolutionary biology—Ellison answers such questions as why human birth is so difficult, why females menstruate, and why males mature later than females.

The books mentioned are usually available in the Museum Shop or via the Museum's Web site, www.amnh.org.

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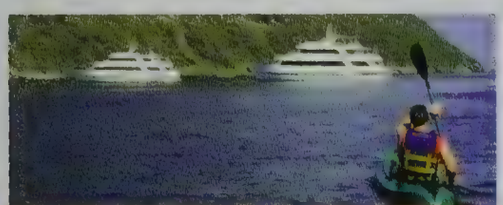

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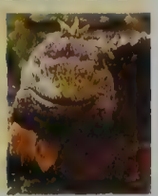

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AT THE MUSEUM

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James Webster with the Museum's cast of a Vesuvius debris flow

Mount Vesuvius, 1944

AP/WORLD WIDE PHOTOS

Upwardly Mobile

A Museum scientist analyzes what's inside volcanoes to predict how high they'll blow.

By Henry S. F. Cooper Jr.

In the Gottesman Hall of Planet Earth is a ten-foot, grayish black cube: a cast of part of a debris flow from Mount Vesuvius that helped bury Pompeii in A.D. 79. Pieces of real rocks that stuck to the latex mold provide the cast with an authentic veneer, and missing bits have been painted in. At the bottom are the remains of a brick column crushed by the weight of the volcanic material.

"It's the stuff that buried the bodies found at Pompeii," says James Webster, a geochemist interested in volcanoes and a curator of earth and planetary sciences in the Museum's Division of Physical Sciences. "The level where the pillar is, is the same layer where the bodies were found. The interpretation is that the eruption, which had been going on for several hours, seemed to calm down, and the people who had left returned to their homes to collect their belongings. Then flow upon flow of pyroclastic [violently ejected] material came pouring down the side of Vesuvius."

Webster collected many of the volcanic rocks displayed in the Hall of Planet Earth. His research may lead to ways of predicting which of the world's 500 to 600 active volcanoes will produce the most explosive eruptions. Clearly the citizens of Pompeii would have appreciated some advance warning of these catastrophic events. So would the neighbors of Indonesia's Mount Tambora in 1815 and Krakatoa in 1883 and those of the Philippines' Mount Pinatubo in 1991, as well as the more than 20,000 Colombians killed by a lahar (a mudflow of hot volcanic material) when Colombia's Mount Ruiz erupted in 1985.

In his laboratory on the Museum's fourth floor, Webster shows me a large blue vessel capable of reproducing the temperatures and pressures corresponding to depths inside Earth where magmas form in the crust and upper mantle. The two-week experiment going on behind the tightly closed hatch has just started. It involves heating and squeezing powdered rock from a lava flow; gauges on the wall indicate that the current pressure is 30,000 pounds per square inch (equivalent to the pressure four and a half miles down) and

that the temperature is about 1,000° C. Webster is trying to remelt the rock particles to measure the concentration of one of the flow's volatiles, sulfur. Volatiles—the water and dissolved gases in magma—are what drive eruptions, propelling the molten material upward and eventually out.

Despite the miniature volcano seething inside the pressure vessel, the laboratory is a quiet place for a talk. Some geologists, Webster tells me, are attempting to predict eruptions by measuring seismic waves (a method that has achieved some success, particularly at Kilauea in Hawaii), while others measure the volatiles released from volcanoes. Webster tries to measure volatiles in the magma *before* an eruption. The most common ones—and those that provide the most explosive force—are water and carbon dioxide. Depending on the composition of the magmas, however, smaller quantities of sulfur, chlorine, and fluorine, as well as traces of nitrogen, hydrogen, and carbon monoxide, may also be involved.

What drives a volcano's explosive force? Ordinary water and carbon dioxide, with a touch of sulfur and chlorine.

The deeper the magma, the greater the pressure and the greater the quantity of volatiles that will be dissolved in it. As magma rises, the pressure decreases and the volatiles increasingly turn to vapor, pushing the magma onward and upward with ever increasing force. The richer the magma is in dissolved volatiles, the faster they are released as gases and the more explosive the eruption. The problem with looking for volatiles in the original melt is that by the time magmas reach the surface, cool into solid lava flows, and find their way into Webster's machine, the rocks have lost their volatiles. It's a little like looking for carbon dioxide in flat ginger ale. As the lava cools and crystallizes, however, crystals that measure between half a millimeter and tens of millimeters in diameter can retain droplets of "melt," or still-molten volcanic glass. The melt hardens as glass inclusions in the lava, trapping the volatiles inside what amount to tiny enclosed bottles and providing the scientists who open them with a measurable source.

One result of discovering this source has been to allow geochemists to take a closer look at the role of some of the less abundant volatiles. "We used to look at the rocks, and when we saw they didn't have much chlorine, we assumed that chlorine was not important," says Webster. "But over the last decade, looking at the melt inclusions, we find higher abundances of chlorine in many cases. One of the things we've been doing at the Museum in the last ten years is looking at the behavior of chlorine-rich magmas, and we've been focusing on volcanoes around the world that have higher chlorine contents."

In particular, Webster and Museum colleague Federica Raia, together with Benedetto DeVivo, of the University of Naples, have been looking at lavas from Somma-Vesuvius (Mount Somma is an older cone that forms a summit and ridge partly encircling Vesuvius). Over the past 25,000 years, Somma-Vesuvius has erupted dozens of times, but only seven or eight of these eruptions have been as catastrophic as the one that buried Pompeii. "We have been looking at melt inclusions in these magmas that date from 3,500 to 14,000 years ago, which is when we believe the break between Somma and Vesuvius occurred," Webster says. "What we have found is that the most highly explosive eruptions—the ones that bury communities and cause the greatest loss of life—show very different ratios of sulfur to chlorine in their melt inclusions and therefore in the magma." He is quick to add that other factors, such as the strength of the rock surrounding the magma, are important too.

Every volcano is different, of course. But Webster and his associates continue to gather data suggesting that an increase of sulfur relative to chlorine in the inclusions could well indicate that an explosive eruption might be in the works at Vesuvius—and possibly elsewhere. Why the ratio of chlorine to sulfur is a factor, however, is not understood.

Another feature of volatiles in magma is that they attach themselves to a number of metals, determining which metals a particular magma will carry along and deposit in underground pipes, veins, and cracks. "So in studying how these hot gases drive volcanic eruptions, one can also see how they concentrate metals like gold and silver and tin and molybdenum," Webster says. In fact, when he first joined the staff of the Museum in 1990, two years after receiving his doctorate from Arizona State University, his research focused on ore and mineral deposits and their transport underground via the same volatiles that make magmas upwardly mobile.

As Webster tells it, "My grandfather, my father's father, was a miner, so whenever we went to visit him in Georgia—and later in Dutchess County, New York—I would go off with Grandpa to the marble or limestone quarries. What was really neat was that in pockets in the rock I could find crystals. He got me started with rocks and minerals, and I've been hooked ever since."

Henry S. F. Cooper Jr., a former staff writer for the New Yorker, *has been visiting the Museum since he was four years old, when his father sat him in a cavity of the Willamette meteorite.*

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MUSEUM EVENTS

APRIL 2

John Burroughs Association literary awards luncheon. Winner of this year's book award: *Swampwalker's Journal: A Wetlands Year,* by David M. Carroll (Houghton Mifflin, 1999). 12:00 noon. For information and reservations, call (212) 769-5169.

Lecture: "Supermassive Black Holes, Quasars, and Their Galaxy Hosts" (Frontiers in Astrophysics series). Astronomer Richard Green. 7:30 P.M., Space Theater, Hayden Planetarium.

APRIL 3

Lecture: "Dinosaur Imagery: The Science of Lost Worlds and Jurassic Art." Collector John Lanzendorf. 7:00 P.M., Kaufmann Theater.

APRIL 4, 5, AND 6

Symposium: "Conservation Genetics in the Age of Genomics." Keynote address by author and activist Jeremy Rifkin, April 4, 7:00 P.M. Scientific presentations April 5–6, 9:00 A.M.–5:30 P.M. Sponsored by the Museum's Center for Biodiversity and Conservation and the Bronx Zoo–based Wildlife Conservation Society. Call (212) 769-5200 or visit research.amnh.org/biodiversity/.

APRIL 12

Lecture: "Redwood Logs, Rubber Ducks, and Loggerheads: What Can Sea Turtles Teach Us About the Ocean?" (Earthwatch at the Museum series). Herpetologist Wallace Nichols. 7:00 P.M., Kaufmann Theater.

APRIL 17

Lecture: "Avoiding a Planet of Weeds: Environmentalism and Democracy in the Twenty-First Century." Journalist Mark Dowie and environmental lawyer William Shutkin. 7:00 P.M., Kaufmann Theater.

APRIL 19

Lecture: "Putting Species Back Into Human Evolution: Why Should Our Evolution Be Different From Other

GIRAUD FOSTER AND NORMAN BARKER

Ammonite fossil, from "Ancient Microworlds," an exhibition of fifty photographs by Giraud Foster and Norman Barker. Akeley Gallery, April 28–September 9.

Animals'?" Physical anthropologist and Museum research associate Jeffrey H. Schwartz. 7:00 P.M., Kaufmann Theater.

APRIL 19 AND 26

Two lectures: "Along the Silk Road," Karen Kane, manager of Museum teaching and learning, April 19; "Ocean Life: A Changing Ecology," senior Museum instructor Lisa Breslof, April 26 (Thursday Afternoons at the Museum series). 3:00 P.M., Linder Theater.

APRIL 23

Lecture: "Atom: An Odyssey From the Big Bang to Life on Earth and Beyond" (Distinguished Authors in Astronomy series). Physicist Lawrence Krauss. 7:30 P.M., Space Theater, Hayden Planetarium.

DURING APRIL

Asian Pacific American Heritage celebration. Free weekend programs (except April 14–15), including films, lectures, performances, and workshops. 1:00–5:00 P.M., Leonhardt People Center. Call (212) 769-5315.

For the Hayden Planetarium course schedule, call (212) 769-5200. For information on field trips and workshops for adults and children, inside and outside the Museum, call (212) 769-5200.

Films at the IMAX Theater: *Shackleton's Antarctic Adventure* (the dramatic story of the 1914–17 British Imperial Trans-Antarctic Expedition) and *Ocean Oasis* (the biodiversity of the Baja California peninsula).

The American Museum of Natural History is located at Central Park West and 79th Street in New York City. For listings of events, exhibitions, and hours, call (212) 769-5100 or visit the Museum's Web site at www.amnh.org. Space Show tickets, retail products, and Museum memberships are also available online.

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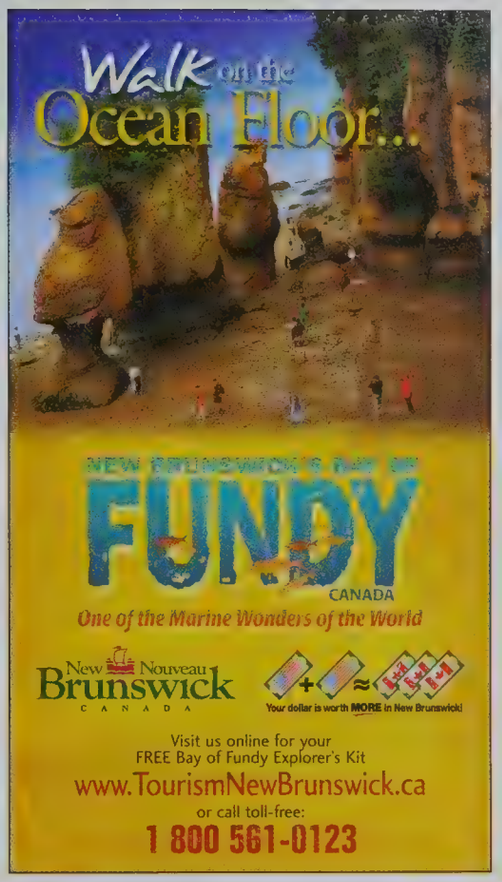
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THE NATURAL MOMENT

Photograph by Mike Severns

Coral Stables

Horses are sometimes confined to corrals, but Bargibant's, or pygmy, seahorses are confined to corals—in fact, to a particular genus of gorgonian coral called *Muricella*, found in Southeast Asia, Indonesia, and Australia. A relative of the pipefish, this tiny seahorse *(Hippocampus bargibanti)*, when full grown, is the size of a pinky fingernail. It spends its adult life with its tail wrapped around the coral's branches, waiting to ambush tiny crustaceans and larvae that drift near enough to be sucked up. With its numerous pink and red tubercles, the pygmy seahorse blends so perfectly with its host that the species was not discovered until 1970, when a zoologist noticed that several were clinging to a *Muricella* in an aquarium.

Like most seahorse species, *H. bargibanti* is monogamous, and couples spend most of their time together. When they mate, they lock together face-to-face, and the female transfers her eggs into the male's abdominal pouch. Within a few weeks, the male grows visibly pregnant. (This pair, with pregnant father at right, was photographed at a depth of 140 feet, off the coast of Indonesia's Komodo Island.) The embryos hatch in his pouch and are brooded there. While male seahorses of larger species may brood as many as a thousand embryos in their pouches, the male pygmy seahorse carries only one or two. As soon as they are expelled from the pouch, the young are on their own.

—Richard Milner

actual size

ENDPAPER

What We Do Best

By Vaclav Smil

YANN ARTHUS-BERTRAND; CORBIS

Simon Karori, Kenyan long-distance runner

What makes us human? A large brain, an upright stride, coherent speech, shared cultures? All of these, of course, and something else. Something that does not command as much admiration as high encephalization, bipedal locomotion, symbolic language, or intergenerational transmission of mores and taboos. The trait that I have in mind is something most people would not even think about listing as truly special, yet we do it better than any organism alive. And having just moved, temporarily, from Canada to tropical China, I have to rely on it heavily to make it through a day. I'm talking about sweat.

I perspire a great deal. Since I dislike air conditioners, I have to depend on my internal thermostat, which tries to keep the body's core temperature from rising as the outside air climbs above 86° F. As long as I sit still, my body's initial thermoregulatory adjustment consists of dilating peripheral blood vessels and shifting additional blood from internal to superficial veins. But as I climb up a steep hill to my apartment—although it seems to me I am crawling, compared with my usual Canadian pace—and as my skin temperature approaches 95° F, I begin to sweat. Not a great deal at first, because I haven't been here long enough to be fully acclimatized. But if I keep climbing, I will lose water at a rate of more than fourteen ounces per square yard of skin (that is, about a cup every twenty minutes). Per unit of skin area, this is about four times more than a horse and nearly twice as much as a camel, two of the most profuse perspirers among mammals.

But even such a rate of cooling, corresponding to a power input of about 500 watts, is not always enough to cool me. During strenuous activity, most fit people will consume energy at ten to fifteen times the rate they do while resting, and they may need to dispose of 600 to 800 watts of heat. For topflight athletes, the rate of energy consumption during exercise can increase up to twenty-five-fold. To avoid overheating, these individuals must dispose of heat at rates exceeding 1,300 watts, and they will perspire about two quarts of water every hour. Fortunately, such high water losses do not require instant replenishment: healthy individuals are not harmed if they can make up their water deficit within the next twelve to twenty-four hours.

Our genes have conserved the sweating capacity we acquired on the seared grasslands of Africa, but for those of us coming from northern climes, it takes a while to turn the flow fully on. Even a fit Englishman trying to run farther than six miles the day after flying from London to Singapore is flirting with dangerously high core temperatures and with heartbeats approaching normally tolerable maxima. But if he keeps exercising moderately, he may start matching the sweating rates of acclimatized locals in just ten days. That, of course, is how all those Scottish laddies, who grew up never enduring a hot day, could sail away and build an immense tropical empire for the Queen.

Many centuries ago, the Tarahumara of northern Mexico took turns running down deer in the middle of the day. Unable to match the Indians' enviable capacity for keeping themselves cool, the animals died of heat prostration. The Kalahari's Basarwa hunted duikers, gemsbok, and zebras the same way, and perhaps some Australian Aborigines simply "thermoshocked" kangaroos. After a week's adjustment, I plan to deploy my sweating capacity in running a sixty-two-mile trail in several segments. As the trail shifts from sea level to more than 3,000 feet, and then down and up again, I will find myself having to use that very human, and truly lifesaving, ability to outsweat every other species.

Vaclav Smil teaches at the University of Manitoba's geography department. His most recent books, both published by MIT Press, are Energies: An Illustrated Guide to the Biosphere and Civilization *(2000) and* Feeding the World: A Challenge for the Twenty-First Century *(2000).*

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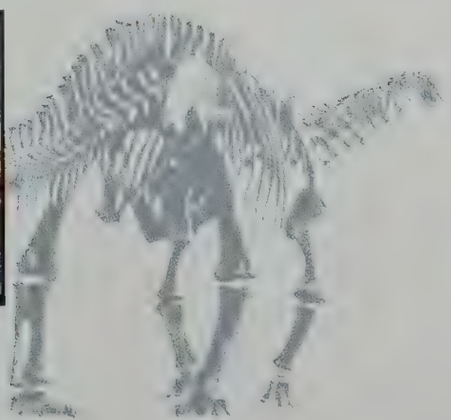

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Tiny drops of honeydew exuded by a bark-dwelling insect are prized by many animals in a beech forest.

BY LAURA SESSIONS

50 MOTHERS AND OTHERS

Rearing human offspring to independence is one of nature's most labor-intensive reproductive tasks. Early human mothers, argues this anthropologist, weren't the only ones bringing up baby.

BY SARAH BLAFFER HRDY

COVER

Female Barbary macaques with a baby. Primate mothering is, to varying degrees, a shared venture.

STORY BEGINS ON PAGE 50

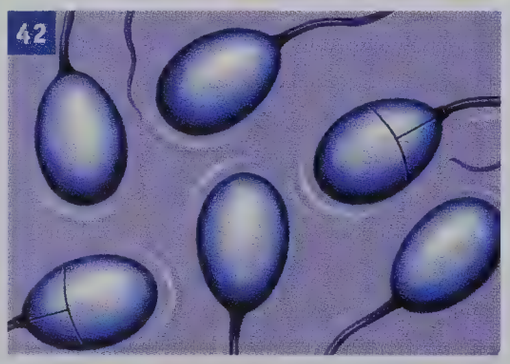
PHOTOGRAPH BY CYRIL RUOSO/BIOS; PETER ARNOLD, INC.

72 THE REWARDS OF CHANCE

Thanks to the random behavior of agitated molecules, a beetle can flex its wings and a clam can open up its shell.

BY MARK DENNY

DEPARTMENTS



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WHERE THE PAST COMES ALIVE

UP FRONT

Others' Day

Probably because I grew up in a part of the world where most families were small and nuclear, I often heard friends remark that nothing in their experience—not the baby-sitting jobs, certainly not complaints from their own overworked mothers, not all of Erma Bombeck's brilliant wisecracks—had quite prepared them for the night-and-day relentlessness of the task of caring for their first baby. (The only person among us who knew the score ahead of time was herself the oldest of eleven. It could truly be said that Kathy had already been a parent.)

A human infant is, of course, about as helpless a creature as one finds in nature. And it needs support for an extremely long time. Mothers and fathers are not born with the skills required. (Basic issues of caretaking sometimes stymie even the experts. Is crib death best prevented by putting the baby down on its back, side, or stomach? The most recent official answer from pediatricians is that the back is safest.) As soon as an infant can crawl, its moment-to-moment existence is threatened by physical dangers. Getting a child past infancy requires unending vigilance, and attending to its social and emotional education is one of life's most challenging long-term commitments. (The writer James Agee once observed that "begetting a child is at least as serious an act as murder." Yet for the most part, we cheerfully opt to reproduce.)

DANNY LYON; MAGNUM PHOTOS, INC.

Humans are flexible creatures, and what we consider the proper and most loving way to bring up a child varies with cultural background, financial circumstances, and individual experience. Yet we are not infinitely flexible. We are mammals, primates with a unique evolutionary history. If our offspring are to survive and behave as social creatures, we must toe a biological bottom line.

In this issue, anthropologist Sarah Blaffer Hrdy ("Mothers and Others," page 50) takes an extended look at that bottom line. Pulling together evidence from social anthropology, endocrinology, and studies of animal behavior, Hrdy bolsters her hunch that the original human family was far from nuclear. As Mother's Day approaches, we can pause to think about not just the traditional honorees but also fathers, siblings, grandparents, aunts, uncles, day-care workers, and foster parents. It may well be that the devoted labors of "others" made it possible for humans to evolve.—*Ellen Goldensohn*

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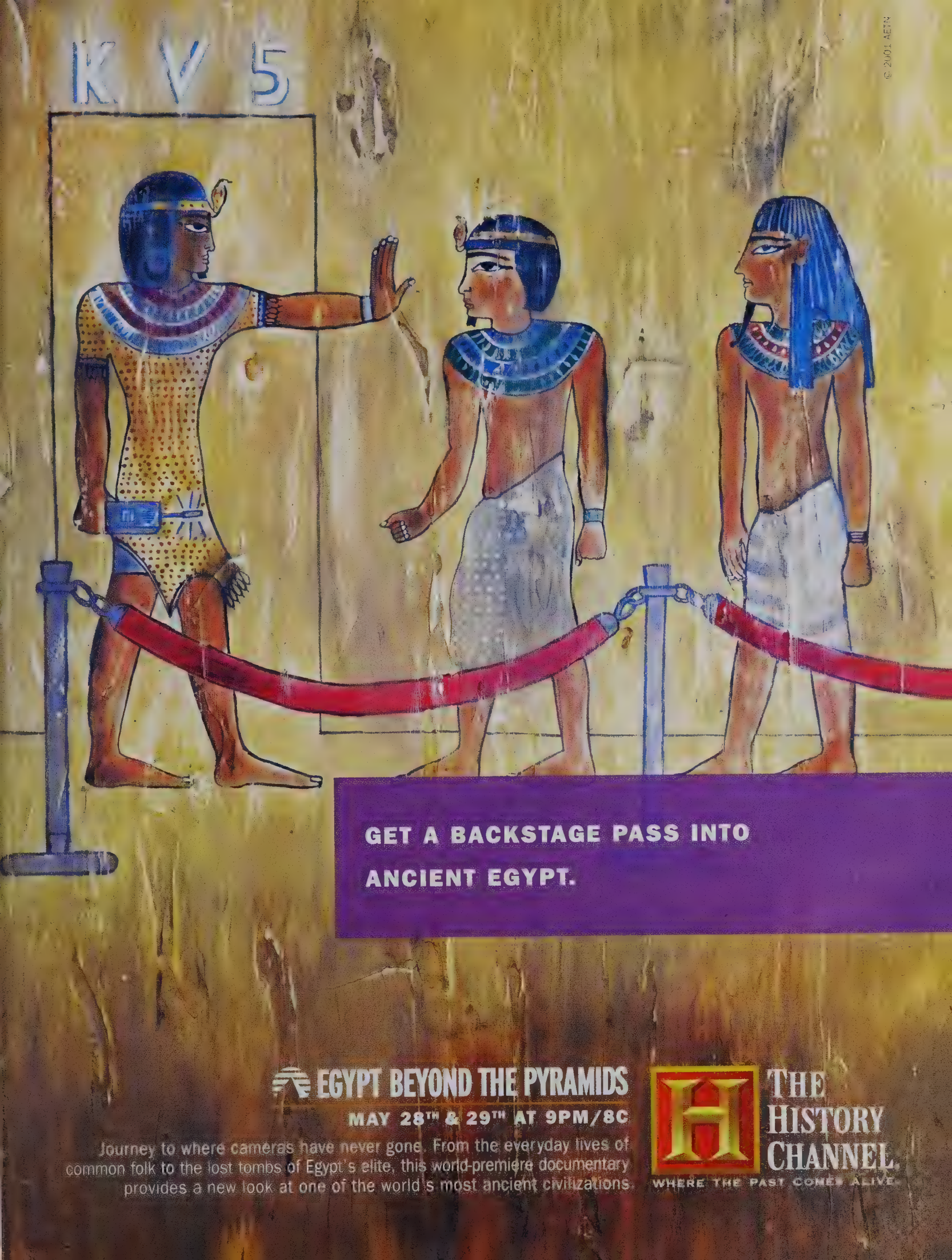

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LETTERS

A Larva By Any Other Name

On page 56 of "A World Apart," by Gregory A. Wray (3/01), two photographs illustrate the drastic morphological change that occurs in a snail at metamorphosis. Unfortunately, the photographs are of two decidedly different types of snails. While the adult nudibranch is correctly identified, the veliger larva is not a nudibranch. Its multispiral, heavily sculptured, darkly colored shell, plus its large four-lobed velum, point to a different type of snail, one of the neogastropods.
Paula M. Mikkelsen, Ph.D.
Division of Invertebrate Zoology
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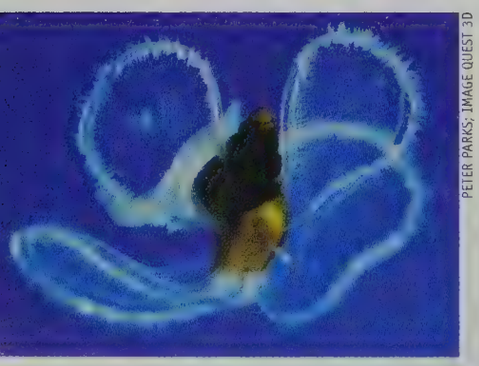


PETER PARKS; IMAGE QUEST 3D

THE PHOTOGRAPHER, PETER PARKS, RESPONDS: Paula Mikkelsen is quite right. The original slide for this photo was mislabeled. It should have been captioned "prosobranch" (not "opistobranch").

Insect Allure

Erik L. Laurent's article on the Japanese fascination with insects ("Mushi," 3/01) was itself fascinating. The note about the author on page 13 ("Contributors") mentions the eating of insects, and I was reminded of an incident that happened in 1946 or '47. I was in the Scientific and Technical Division at MacArthur's headquarters, where we had the responsibility of overseeing Japanese research. One project was on the use of silkworm pupae after the silk had been unwound. Unfortunately, the research had to be discontinued because the young women doing the work ate all the pupae. Food was rather short at that time, and the pupae were essentially cooked in the water used to loosen the silk.
John H. McClendon
via e-mail

The author writes about Japan, but playing with insects is fairly universal in Asia. When I was a child in Hong Kong, we were always staging fights between belligerent insects, which were sold by vendors sitting outside the school gate.
A. Zee
Santa Barbara, California

Eve and Adam

In "The Evolutionary Front" (3/01), Carl Zimmer writes that "a father cannot contribute mitochondrial genes to a child, because mitochondria in sperm can't enter the egg cell." Yet in "Symbionts and Assassins" (7/00–8/00), Guy Brown writes, "When a sperm penetrates an egg cell during conception, it delivers a full load of nuclear DNA but only a few or no mitochondria." If Brown is correct and some mitochondria can be passed from father to child, does that shed doubt on the "mitochondrial Eve" date of 170,000 years?
Adam Klein
Jackson, New Jersey

GUY BROWN RESPONDS: There has been some scientific debate over the past ten years about whether any mitochondrial DNA is inherited paternally. It had been assumed that there was no paternal inheritance, but then some work on mice indicated there was a paternal contribution, and studies of egg fertilization showed that significant numbers of sperm mitochondria did enter the egg. More recent studies, however, have indicated that sperm mitochondria entering the egg are subsequently destroyed, and the pendulum of opinion has swung back. I was reflecting the current scientific uncertainty by saying that the sperm might deliver "only a few or no" mitochondria.

Hominid Bones

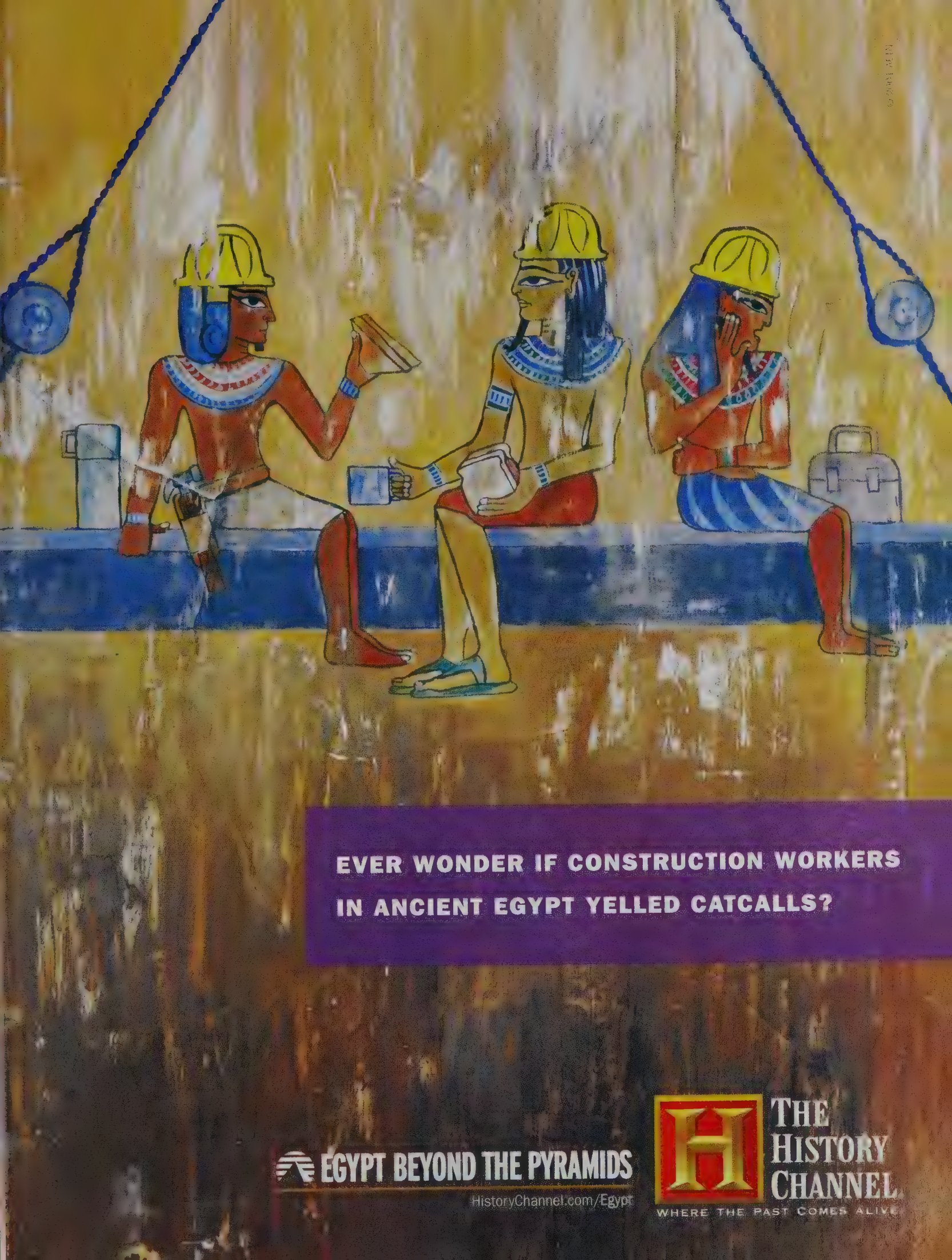
After reading "The Scavenging of 'Peking Man,'" by Noel T. Boaz and Russell L. Ciochon (3/01), I wondered if there were any planned or in-process efforts to replicate the DNA of *Homo erectus* and/or *Homo habilis,* as has recently been done with Neanderthal DNA.
Kathleen McVey
via e-mail

RUSSELL L. CIOCHON REPLIES: Chances for the preservation of DNA decrease with the specimen's age. Neanderthal fossils are all less than 100,000 years old, and even so, only two have yielded DNA. *Homo erectus* fossils are three to fifteen times older; in addition, none have been well enough preserved to provide any DNA. No fossils of "Peking man" are available for DNA testing, as all of the originals have been lost.

Dislodged Beavers

In "In the Field" (3/01), Peter J. Marchand writes that beavers "show little inclination to chisel through" the ice of a pond and emerge from their lodges during winter. Here on the U.S.-Canadian border along the Saint Lawrence River, I have been observing six beaver colonies this winter, and beavers from five of them have been out frequently to harvest trees and brush. The other colony happens to be the deepest. I suggest that beavers in shallower ponds, less than three feet deep, are more likely to make or find holes in the ice created by running waters that are, in turn, caused by holes in the dam that they or otters might make.
Bob Arnebeck
Wellesley Island, New York

Natural History's e-mail address is nhmag@amnh.org.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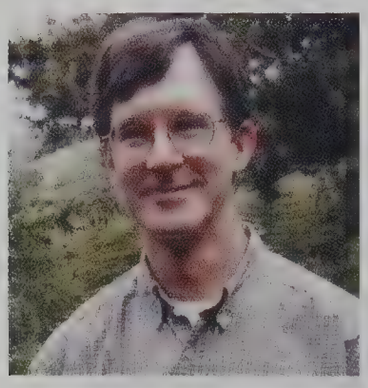
CONTRIBUTORS

It was a picture showing the bacterium *Vibrio harveyi* glowing in the dark that drew **Bonnie L. Bassler** ("Tiny Conspiracies," page 16) to study cell-to-cell communication in bacteria. At the time, she was just finishing her doctorate in biochemistry and wanted to do research in genetics. She thought *V. harveyi* would make an ideal subject because she could induce mutations that affected luminescence and then simply turn off the lights in the room to identify the interesting mutants. "After eleven years of studying the 'languages' of this species," she says, "I realize the phenomenon is slightly more complicated than I first suspected. However, making the mutants is still fun." Bassler is an associate professor in the department of molecular biology at Princeton University.

An anthropologist with a long-standing interest in the natural relationships among males, females, and their offspring, **Sarah Blaffer Hrdy** ("Mothers and Others," page 50) began her research in the 1970s with a nine-year study of Hanuman langurs, a species that Indians regard as sacred. Her evolutionary perspective on families has resulted in two previous major essays for *Natural History*: "Daughters or Sons" (April 1988) and "Natural-Born Mothers" (December 1995). Hrdy (pictured with her son, Niko) is professor emerita of anthropology at the University of California, Davis, and the author of four books, including, most recently, *Mother Nature: A History of Mothers, Infants, and Natural Selection* (Pantheon Books, 1999).

Laura Sessions ("New Zealand Sweet Stakes," page 64) first read E. O. Wilson's article "The Little Things That Run the World" as an undergraduate biology student and says she has been looking for examples ever since. Honeydew insects in the southern beech forests of New Zealand fill the bill. Sessions moved to New Zealand from the United States in 1996. After finishing her master's degree at the University of Canterbury in Christchurch—on the effects of Australian brush-tailed possums on New Zealand plants—she enrolled in a doctoral program there in science communication. Sessions leads natural history tours of New Zealand for American students and recently visited South Georgia and other subantarctic islands, where she had an opportunity to "play with the penguins and sea lions."



After writing his doctoral dissertation on slug slime, **Mark Denny** ("The Rewards of Chance," page 72) turned his attention to the plants and animals that live on wave-swept shores. Currently the DeNault Professor of Marine Sciences at Stanford University, Denny conducts fieldwork at Stanford's Hopkins Marine Station in Pacific Grove, California. Together with Steven Gaines, he wrote *Chance in Biology: Using Probability to Explore Nature* (Princeton University Press, 2000). Their interest in chance began while attempting to predict the toughest conditions intertidal organisms could tolerate. Denny reports that for a biologist (not a mathematician or statistician), it feels strange to have written a book about probability theory—especially, he says, when he mentions it to fellow biologists and then "observes them get a wary look in their eye and edge away."

John Serrao ("The Natural Moment," page 88) grew up in the borough of Queens, New York City, where he pursued his passion for living things by hunting black widow spiders around Jamaica Bay and collecting cicada-killing wasps in his backyard. After receiving an M.S. in Science and Environmental Education from Cornell University, Serrao (pictured here with a two-month-old black bear) began his career as a professional naturalist, leading nature programs for schools and communities near his home in the Pocono Mountains. His wildlife photography has appeared in dozens of magazines and field guides and in nearly a hundred nature books. Serrao's most recent book is a self-published photographic guide, *The Reptiles and Amphibians of the Poconos and Northeastern Pennsylvania* (J. S. Publications, 2000).

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IN SUM

SIS'S CHICKS Brood parasitism—tricking another mother into incubating one's eggs—is particularly common in ducks. A female duck simply lays her eggs in the nest of another duck, leaving the host mother to care for them. It's a good deal for the parasitic bird: she avoids the energetically costly business of incubating and raising her own chicks and also avoids being a sitting duck for predators.

VICTORIA MCCORMICK; ANIMALS ANIMALS

Goldeneye with chicks

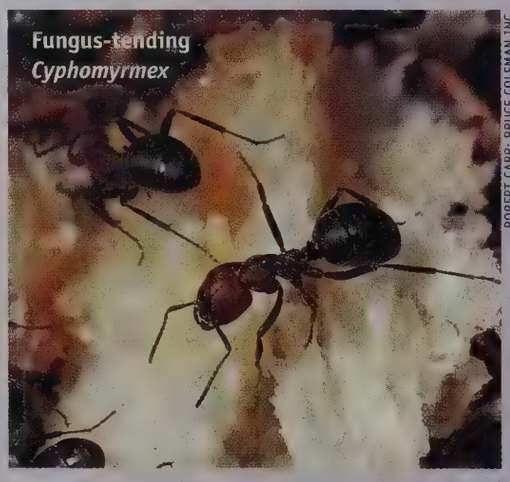
If the host and parasite are closely related, the cost of caring for these extra offspring would be outweighed by the genetic benefit to the group. Zoologists Malte Andersson and Matti Åhlund, of Sweden's Göteborg University, studied this kin-selection hypothesis among female goldeneye ducks *(Bucephala clangula)* by exploring whether the birds parasitize only individuals to which they are closely related.

Without harming the developing embryos, the researchers drew small albumen samples from goldeneye eggs and looked for genetic markers specific to each mother. Andersson and Åhlund found that the hosts and parasites were, in fact, more closely related than one would expect if nests were selected by chance. Female goldeneyes return to their birthplace to lay their eggs, so are they simply more likely to nest—and parasitize nests—in the same area, or do the ducks recognize and target their relatives? The scientists discovered that females most often parasitized the nests of their mothers and sisters and that female relatives spent more time together than random female pairs did. In addition, the more closely related the host-parasite pair, the greater the number of extra eggs a parasite laid in a host's nest—suggesting that a near-relative host was more amenable to the invasion. ("Host-Parasite Relatedness Shown by Protein Fingerprinting in a Brood Parasitic Bird," *Proceedings of the National Academy of Sciences* 97:24, 2000)—*Kirsten L. Weir*

POACHED FUNGI Processions of foliage-toting leaf-cutter ants are common in the rainforests of Central and South America. When the ants return to their nests, they don't eat the leaves they have collected but use them to feed the nutritious fungi that they cultivate in underground chambers. Now scientists have discovered a new ant species of the genus *Megalomyrmex* that is incapable of growing its own fungi but has evolved to steal the fungus farmers' carefully tended harvests.

Biologist Rachelle M. M. Adams, of the University of Texas at Austin, and colleagues studied this thievery-prone species both in the field and in the laboratory. Native to central Panama, it raids nests of *Cyphomyrmex longiscapus* ants, driving out the fungus growers and taking over the colony.

Some *Megalomyrmex* species invade colonies of fungus growers and live peacefully with them as parasites. But members of the newly discovered species invariably attack all the original inhabitants by pulling at their legs and antennae and perhaps by excreting venom.


ROBERT CARR; BRUCE COLEMAN INC.

Fungus-tending *Cyphomyrmex*

Unable to defend themselves, the surviving *C. longiscapus* ants abandon their broods and flee the nest. The predaceous invaders consume the fungus and, researchers suspect, feed the stolen larvae to their own broods.

The nest raiders may do some light gardening, maintaining healthy fungus growth for a while. But they don't add necessary nutrients to the high-maintenance gardens, so the fungi eventually become depleted and the "agro-predators" must seek out and take over a new nest. ("Agro-Predation: Usurpation of Attine Fungus Gardens by *Megalomyrmex* Ants," *Naturwissenschaften* 87, 2000)—*Kirsten L. Weir*

ROCK-CLIMBING FISH Salmon swim upstream to spawn, sometimes leaping over low waterfalls, but can any fish climb a wet, slippery, five-story cliff? A team of Brazilian ichthyologists, headed by Paulo A. Buckup, of the Brazilian National Museum and the Federal University of Rio de Janeiro, has observed a species of the South American darter *(Characidium)* that routinely performs this seemingly impossible feat.

CLAUDIO ZAMPROGNO

Characidium ascendi

The researchers observed the waterfall-climbing abilities of the inch-and-a-half-long fish in the swift freshwater streams of Espírito Santo in eastern Brazil. Using their two large pairs of long, flat, stiff-rayed fins, the darters cling to the base of the vertical rock surface while still underwater, then inch themselves upward with strong lateral movements. Their flat, scaleless bellies and slender, elongated bodies facilitate the process. Resting for a few minutes between each effort, they are able to gradually ascend a fifty-foot cliff beneath a waterfall. The same adaptations that enable the darters to cling and climb also enable them to recolonize upstream areas after being washed downstream by flash floods. The scientists think this behavior helps maintain populations in the isolated uplands, where, it seems, more species of darters have evolved than in the lowlands.

Other kinds of fishes, notably some tropical gobies and Asian loaches, which also have the ability to climb tall waterfalls, have independently evolved fin and body shapes similar to those of the darters. ("Waterfall Climbing in *Characidium* (Crenuchidae: Characidiinae) From Eastern Brazil," *Ichthyological Exploration of Freshwaters* 11:3, 2000)—*Richard Milner*

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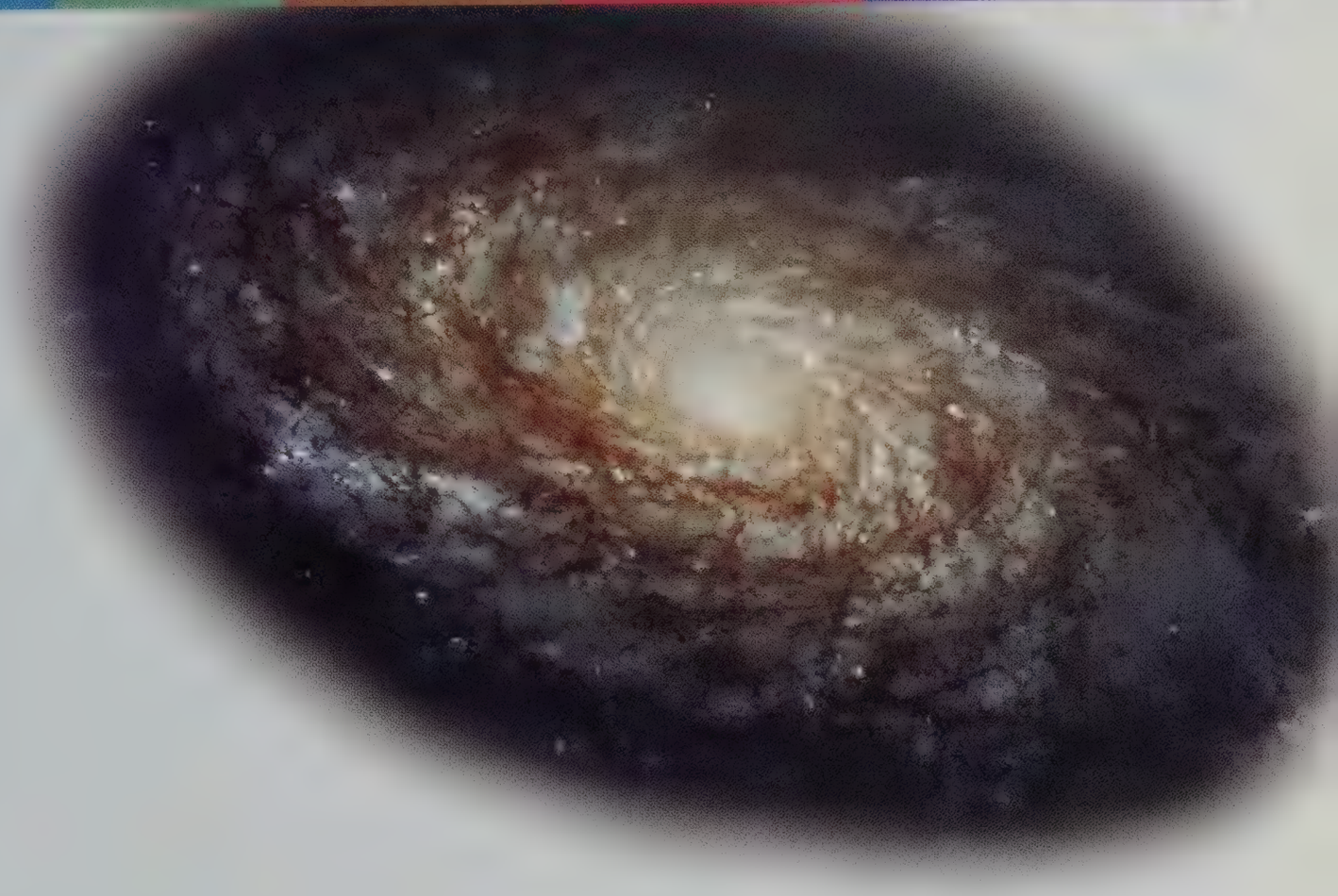

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FINDINGS

Tiny Conspiracies

Cell-to-cell communication allows bacteria to coordinate their activity.

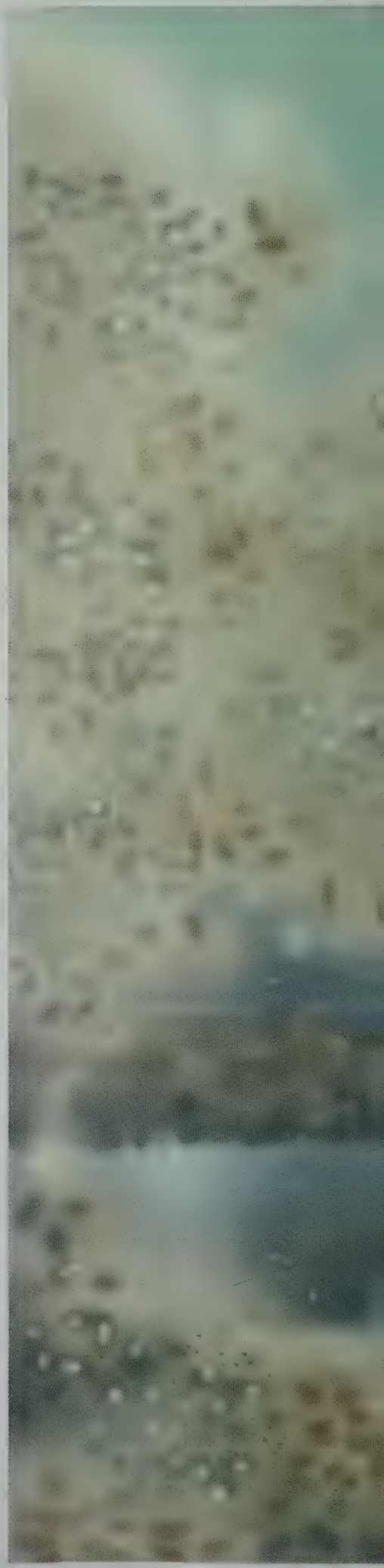
By Bonnie L. Bassler

Bacteria have adapted to a huge range of environments on earth, surviving and multiplying in and on plants and animals, in rock layers deep beneath the surface, in searing desert soils, under polar ice, and under extremely high temperatures and pressures in thermal vents on the ocean floor. During the past decade, we have begun to realize that the success of these tiny, single-celled organisms may depend in large part on their ability to converse with one another using chemical signals. Cell-to-cell communication allows bacteria to coordinate their activity and thus enjoy benefits otherwise reserved for multicellular organisms.

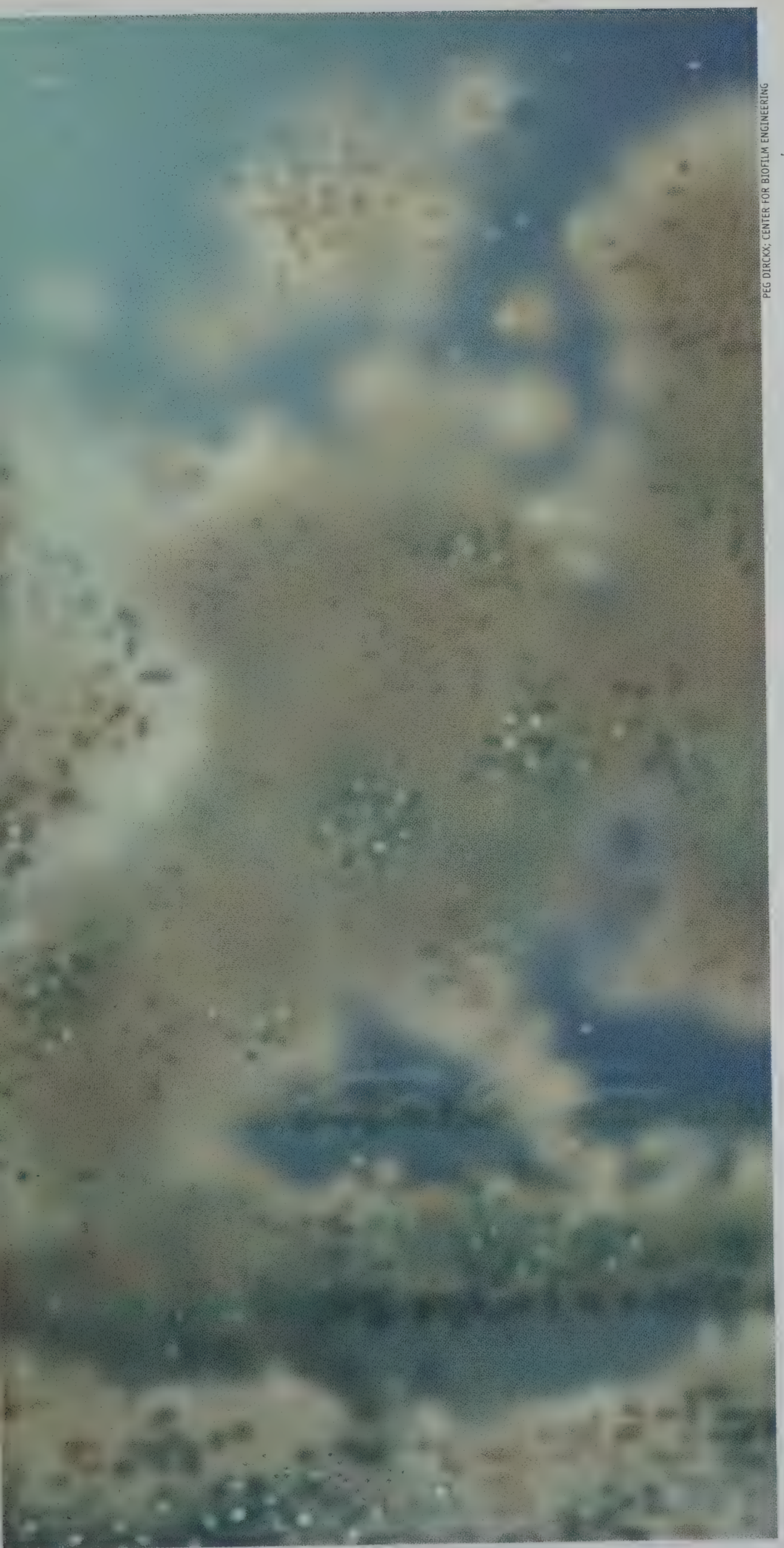
By means of a process called quorum sensing, bacteria are able to detect when they are assembled in large numbers as opposed to when they are essentially alone. They may then adjust their behavior accordingly. Bacteria alert one another to their presence by releasing chemical molecules known as autoinducers. When a chemical of this type becomes sufficiently concentrated in the environment (for example, in an organ such as the lungs or intestinal tract), bacteria that are sensitive to it respond by turning on genes that regulate the production of certain proteins. The newly manufactured proteins, in turn, affect the behavior of the bacteria, which take advantage of one another's presence in their efforts to survive and proliferate.

Until recently, the exchange of chemical signals was assumed to be a trait characteristic of "higher," multicellular organisms. Researchers knew of only a few cases of bacterial cell-to-cell communication and considered them the exception rather than the rule. But now scientists are realizing that this capacity is not only common but critical for bacterial survival and interaction in natural habitats.

The phenomenon of quorum sens-



Artist's concept of a biofilm, a bacterial community that organizes itself in part through cell-to-cell chemical signals. Attached to such surfaces as intestinal linings, biofilms have channels that allow nutrients to reach the individual residents.



PEG DIRCKX; CENTER FOR BIOFILM ENGINEERING

ing was first discovered in two species of bioluminescent marine bacteria, *Vibrio fischeri* and *V. harveyi*. Both of these glow-in-the-dark organisms produce light only when their quorum-sensing ability notifies them that they have reached a high cell density. They then manufacture luciferase, an enzyme concoction that facilitates a light-producing biochemical reaction. Although the two species are quite closely related, they inhabit very different niches in the ocean. *V. fischeri* lives in symbiotic association with a number of marine animals, producing light that host animals use for such purposes as luring prey, scaring off predators, and attracting mates. In return, *V. fischeri* gets to reside in the hosts' specialized light organs, where it is provided with amino acids and other nutrients. *V. harveyi,* by contrast, is a free-living organism, and no one has yet figured out what advantage it derives from emitting light.

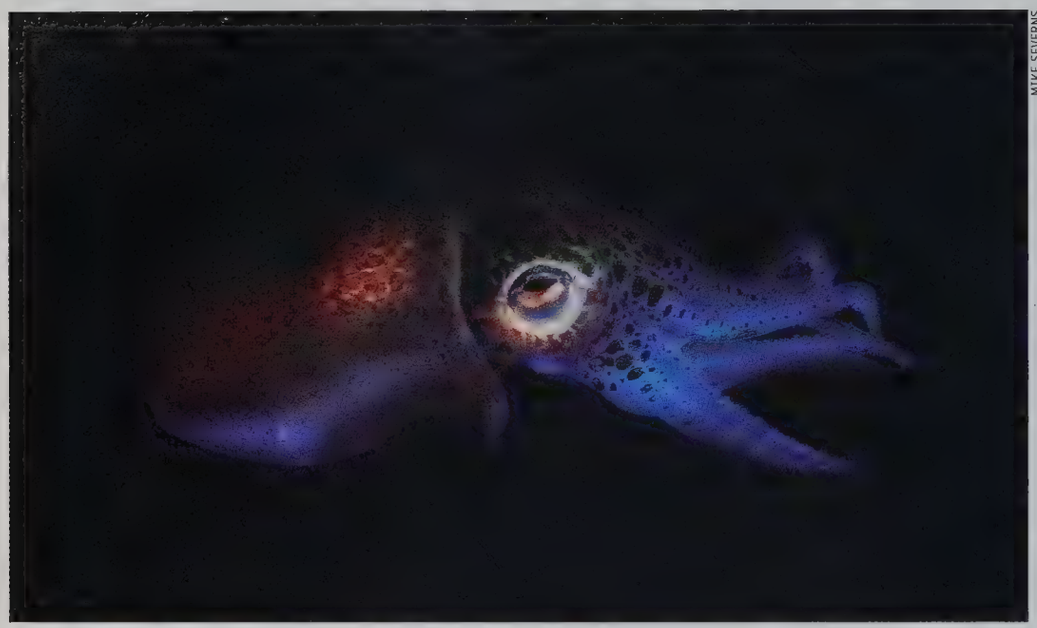
By means of a process called quorum sensing, bacteria are able to detect when their population has reached a high density.

One of *V. fischeri*'s most fascinating associations is with certain bobtail squids of the genus *Euprymna,* the best studied being the Hawaiian bobtail squid. Living in knee-deep coastal waters, this small creature buries itself in the sand during the day and comes out to hunt after dark. Its lifestyle makes the squid especially vulnerable to predation on clear, bright nights, when light shining on the animal from the moon and stars could cause it to cast a shadow and tip off predators patrolling beneath it. But through an alliance with *V. fischeri,* the squid has evolved a light organ that serves as a camouflaging mechanism. The amount of light emitted from this organ, located on the underside of the creature's body, is controlled by an iris-

like structure. The squid senses the intensity of light from the sky and regulates its light organ accordingly, so that the animal, seen from below, more or less matches the background.

The squid's light is produced by the symbiotic bacteria inhabiting the light organ. After a baby squid hatches, *V. fischeri* bacteria in the seawater swim through ducts leading into the immature light organ, where the hospitable conditions enable them to multiply. There the bacteria live suspended in fluid and, as part of their normal behavior, secrete an autoinducer (the chemical that signals their presence) into it. The bacteria interpret a threshold concentration of this chemical as their cue to switch on the production of light. In effect, *V. fischeri* bacteria alert one another that they are inside a suitable host. When dispersed in the ocean water, however, the bacteria and their autoinducer chemicals never reach critical concentrations. Then again, the bacteria probably do not gain anything by emitting light outside the squid.

A remarkable part of this exquisite symbiosis is the way the squid keeps the bacterial culture fresh within its light organ. At sunrise, when the squid prepares to bury itself in the sand for a day of sleep, so many bacterial cells are living in its light organ that the animal cannot supply them all with adequate nutrients. The squid circumvents this problem by pumping out about 95 percent of the *V. fischeri*. This also reduces the level of autoinducer in the light organ below the critical threshold and causes the bacteria remaining within to stop producing light. The pumping is tuned to the squid's circadian rhythm and is activated only at sunrise. As the day goes by, the bacteria begin to divide, their numbers increase, and more autoinducer accumulates. By nightfall, the light organ is "on" again, ready to do its job.



MIKE SEVERNS

A Hawaiian bobtail squid owes its luminescence to *Vibrio fischeri* bacteria housed in an internal light organ. The bacteria secrete a chemical that, when it has accumulated in sufficient concentration, stimulates them to glow.

Quorum sensing is not restricted to glow-in-the-dark marine bacteria. In the past decade, scientists have found it in many other species, with variations in the autoinducer molecules secreted, the means by which they are detected, the biochemical reactions they trigger, and the behavior they regulate. For example, quorum sensing controls the production of virulence factors (toxins and other disease-causing agents) in numerous human and plant pathogens that have a clinical or agricultural impact. Invading bacteria may improve their odds of overcoming a host's defenses by releasing their virulence factors simultaneously and only when they are present in great numbers. A premature release might tip off the host's immune system.

In natural environments, bacterial species compete with one another for nutrients, for entry into hosts, and for survival under hostile conditions. Many bacterial species produce antibiotics—chemical compounds to which they themselves are immune but that kill their competitors or impede their growth. Quorum sensing enables the bacteria to coordinate the release of these antibiotics in high doses.

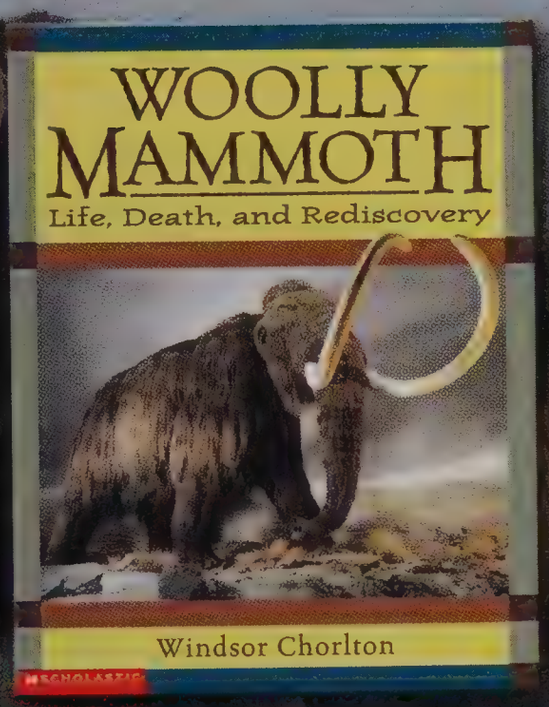
By releasing their toxins simultaneously, invading bacteria may improve their odds of overcoming host defenses.

Quorum sensing also enhances the ability of some bacteria to acquire DNA fragments that, because of the death of some of their fellows, are up for grabs in the environment. These DNA fragments are a useful resource for repairing mutated or damaged chromosomes. Only where there is a concentrated population of bacteria is there likely to be any substantial amount of free DNA available. In this case, quorum sensing turns on the machinery that enables cells to take in this DNA.

Bacterial mating, which creates a more diverse array of individuals and can spread advantageous genes through a species, seems to employ quorum sensing as well. The process involves donor cells and recipient cells. We know that in *Agrobacterium tumefaciens,* a species that causes tumors in susceptible plants, the donors communicate with one another through quorum sensing, but exactly what function this serves is not yet understood.

A READING EXPERIENCE OF MAMMOTH PROPORTIONS

WINDSOR CHORLTON



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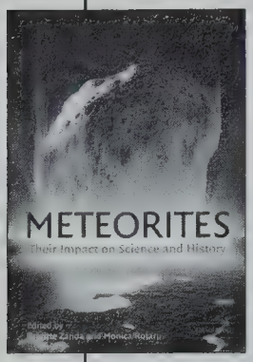

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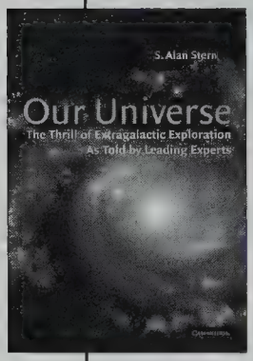

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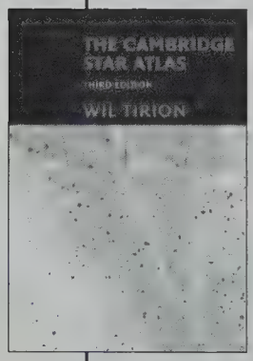

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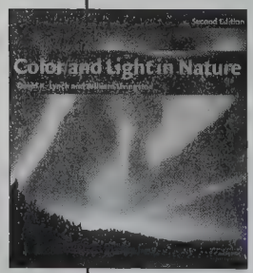

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Often bacteria live in biofilms, or communities attached to a surface such as a rock in a pond or the lining of an intestine. A biofilm is surrounded by a polymer coating, or shield, that keeps the bacteria from drying out and that also resists antibiotics and other environmental assaults. The bacterial community is typically made up of several different species; as in a human metropolis, each member of the community—usually each species—has a specific job. One member, for example, may be responsible for producing the enzymes and molecular building blocks needed to create the polymer shield. Within the biofilm is a network of channels that allow water and nutrients to reach the resident bacteria and permit waste products to flow out. At least in some cases, proper formation of these channels has been shown to be dependent on quorum sensing, although the details of how this is controlled remain to be worked out.

Many bacteria are known to produce and detect several different autoinducers. For example, recent studies show that the free-living luminous bacterium *V. harveyi*, in addition to having the quorum-sensing system that enables it to "turn on" its glow, has a separate system that involves another autoinducer. This second chemical signal

***Yersinia pestis* (the bubonic plague bacterium), right, and *Salmonella typhimurium* (one cause of food poisoning), below, are among the bacterial species known to produce and recognize a type of interspecific chemical signal.**

has been found in a variety of other bacteria as well. These and other findings have led to speculation that this widespread molecule is the basis of a common "language," a bacterial Esperanto providing communication between species.

The capacity to distinguish signals both from its own kind and—through a more universal code—from others could provide a population of a particular bacterial species with valuable information. It could learn not only the cell density of its own population but also whether or not it was sharing its habitat with other species and even whether its own kind was in a majority or a minority at any given time. By adjusting its behavior, this population could then make the most of the prevailing conditions.

Different species may be able to communicate with one another using a common "language," a bacterial Esperanto.

Many bacteria that infect humans

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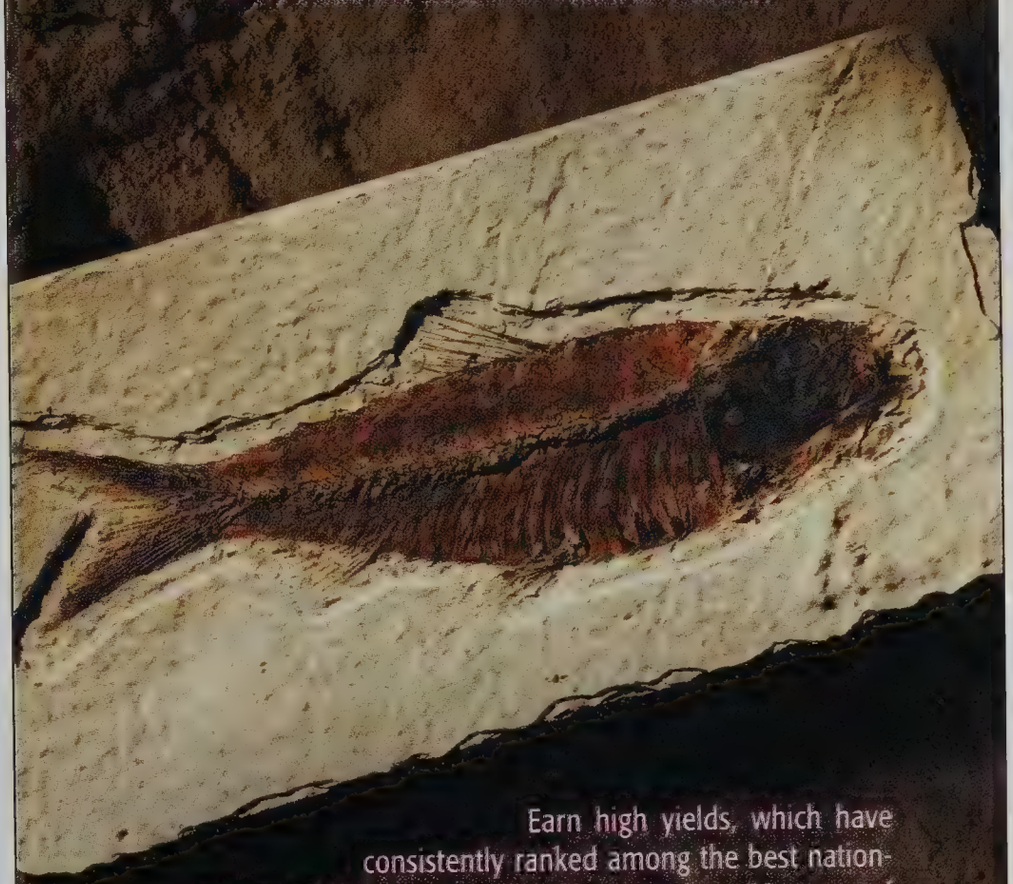

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have now been shown to produce the interspecies signal molecule. They include *Escherichia coli* (food poisoning), *Salmonella typhimurium* (food poisoning), *S. typhi* (typhoid fever), *Haemophilus influenzae* (pneumonia, meningitis, sepsis), *Helicobacter pylori* (peptic ulcers, stomach cancer), *Borrelia burgdorferi* (Lyme disease), *Neisseria meningitidis* (meningitis), *Yersinia pestis* (bubonic plague), *Campylobacter jejuni* (food poisoning), *Vibrio cholerae* (cholera), *Mycobacterium tuberculosis* (tuberculosis), *Enterococcus faecalis* (endocarditis, urinary tract infections), *Streptococcus pneumoniae* (pneumonia, ear inflammations), and *Staphylococcus aureus* (pneumonia, endocarditis, septicemia, toxic shock syndrome, meningitis, food poisoning). While for the most part the specific function served by the autoinducer in these bacteria is not yet known, there is mounting evidence that, at least in some cases, it increases virulence.

The explosion of research in quorum sensing, especially in pathogenic bacteria, is pointing the way to new biotechnological applications. If therapies could be developed that manipulate or disrupt quorum sensing, such drugs would constitute a new class of antibiotics. A new broad-spectrum antibiotic might result, for instance, if a way can be devised to undermine the interspecies signaling system.

DENNIS KUNKEL, PHOTOTAKE

When bacteria mate, as shown here for *E. coli*, a donor cell transmits DNA through a tube. In some species, donor cells communicate with one another through chemical signals, but the function this serves is not understood.

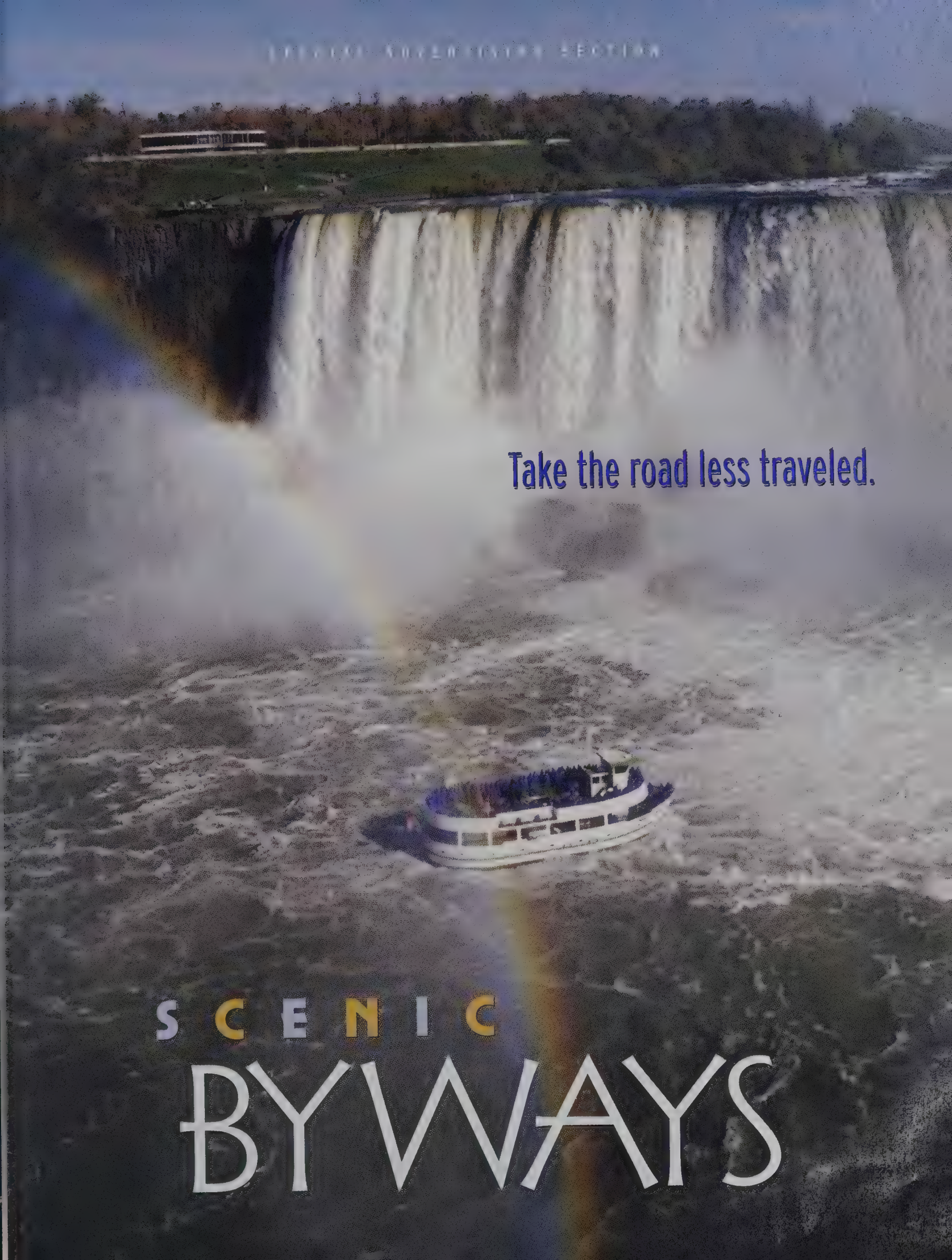
Some novel research is focused on designing molecules that are structurally similar to autoinducers. The idea is to make a molecule that binds to the autoinducer detector of a particular bacterial species, blocking its ability to sense the appropriate signal molecule. This would prevent pathogenic bacteria from recognizing when they are assembled in great numbers and would thus avert the process that is normally triggered. Another approach is to design drugs that specifically interfere with the enzymes involved in synthesizing autoinducers, thus preventing the bacteria from sending out their signal molecules.

In some cases, host organisms already seem capable of manipulating quorum-sensing systems to their own advantage. For example, *Pseudomonas aeruginosa,* a bacterium present in soils and wetland habitats, poses a threat of infection to people already debilitated by cystic fibrosis, burns, cancer, or other conditions. By detecting and responding to autoinducer signals, the victim's body may be able to hinder the secretion of this bacterium's toxins. In other cases, hosts appear to produce molecules that mimic, and in some way interfere with, the quorum-sensing signals. This has been observed in some plants and algae.

If therapies could be developed that manipulate or disrupt quorum sensing, such drugs would constitute a new class of antibiotics.

While much applied research is directed toward finding ways to disrupt quorum sensing, the process can also be exploited in a positive way. For example, cell-to-cell communication may enhance the production of antibiotics. By finding ways to promote quorum sensing, scientists may discover how to improve the commercial production of natural antibiotics, enzymes, and other biochemicals useful in the prevention and treatment of disease, for the protection of food sources, and in industrial processes.

Whatever the practical applications, the investigation of quorum sensing promises to provide biologists with insights into a key step in the evolution of multicellular organisms. An appreciation of the molecular mechanisms that govern this bacterial process will lay the foundation for a better understanding of the development of organs and of cell-to-cell interactions and information processing in higher organisms. □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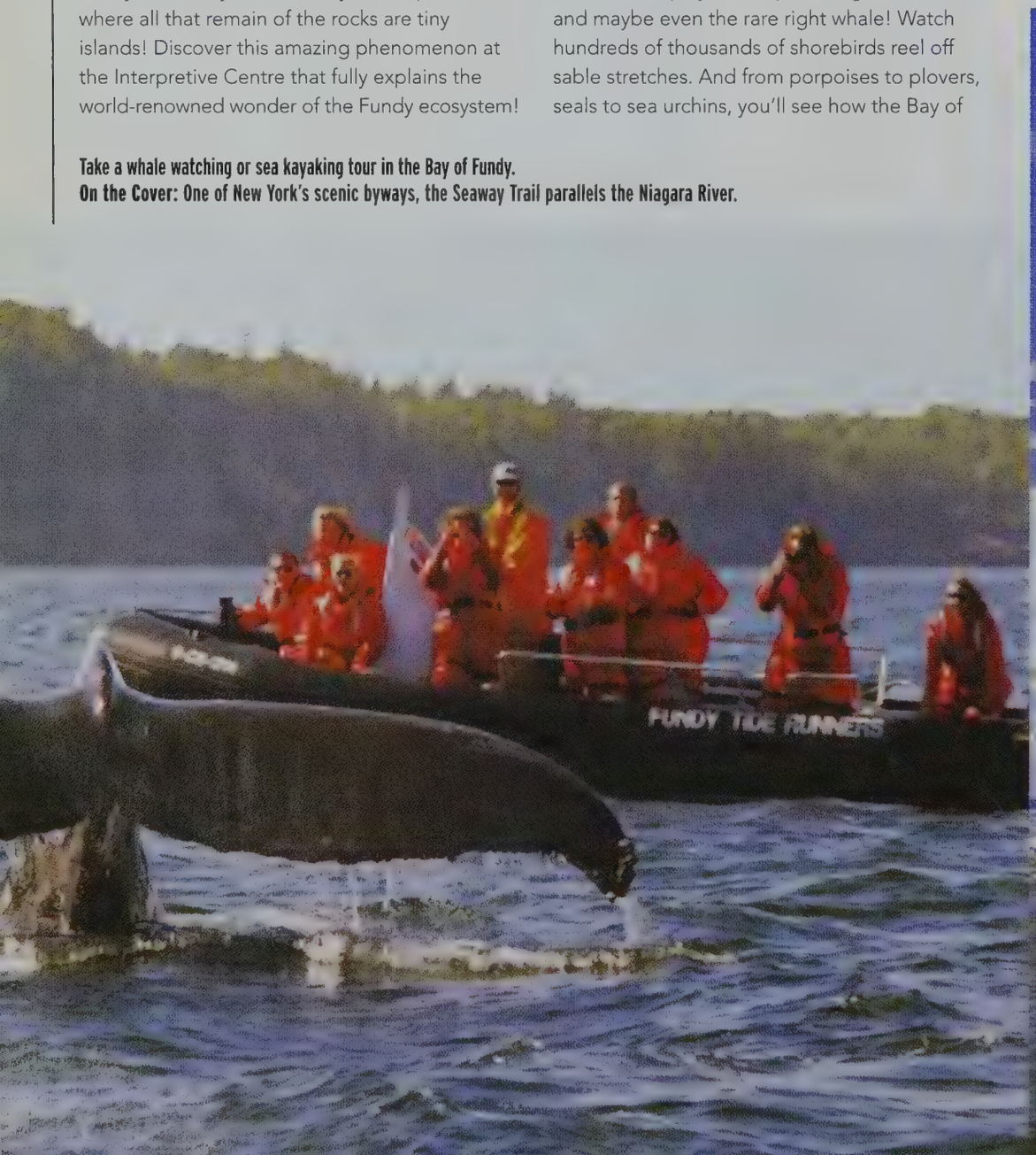
Hike, bike, or drive the amazing Fundy Trail, and learn the secrets of Fundy's tidal ecosystem at Fundy National Park. Explore the sea caverns of St. Martins. View some of the oldest visible rocks on earth in Saint John, the Fundy City. And feel the thrill of the Reversing Falls rapids, where the Fundy tides meet the mighty St. John River! Plus, you can explore their great outdoors with natural sites, national and provincial parks, and amazing trails. New Brunswick has incredible

Take a whale watching or sea kayaking tour in the Bay of Fundy.
On the Cover: One of New York's scenic byways, the Seaway Trail parallels the Niagara River.



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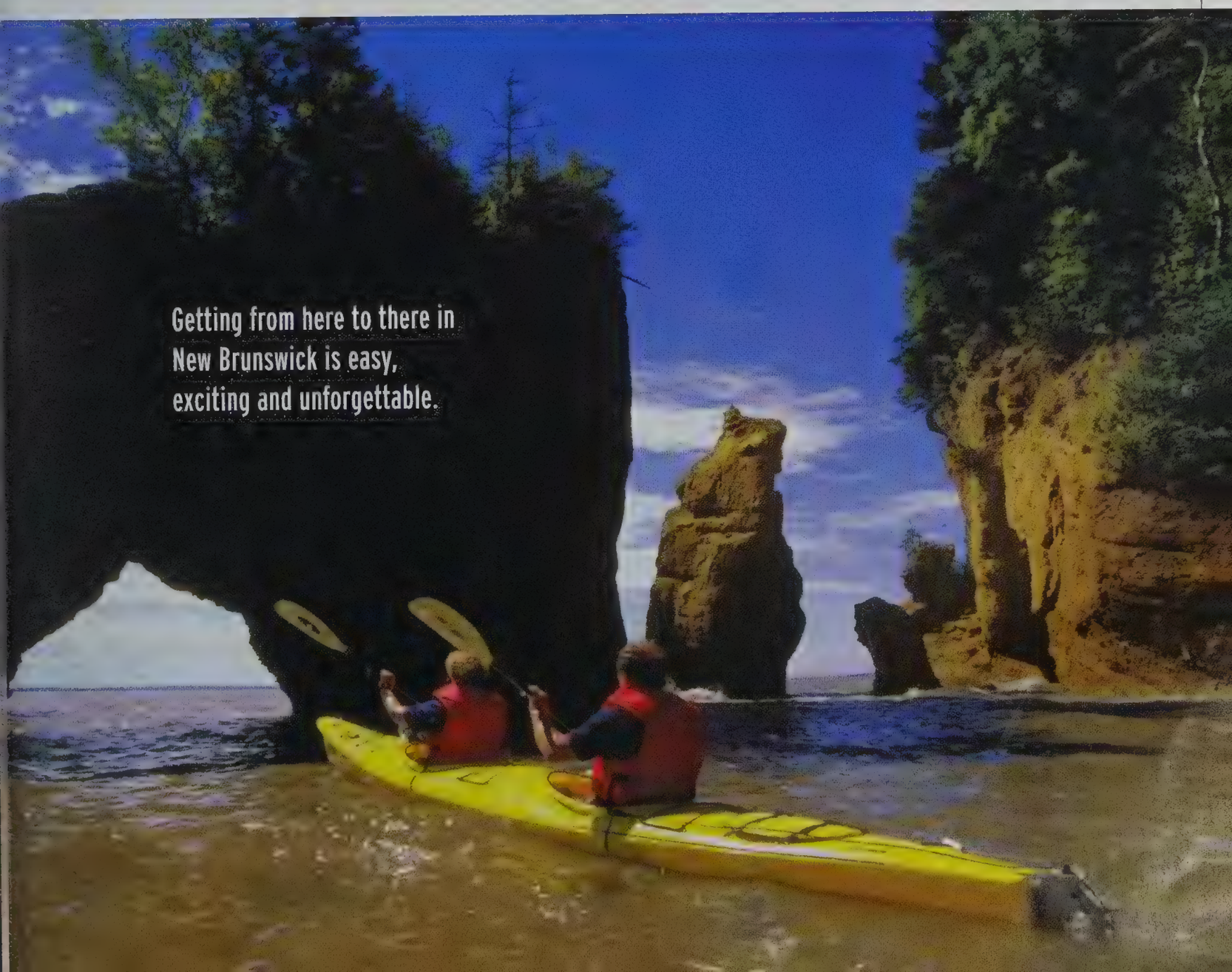
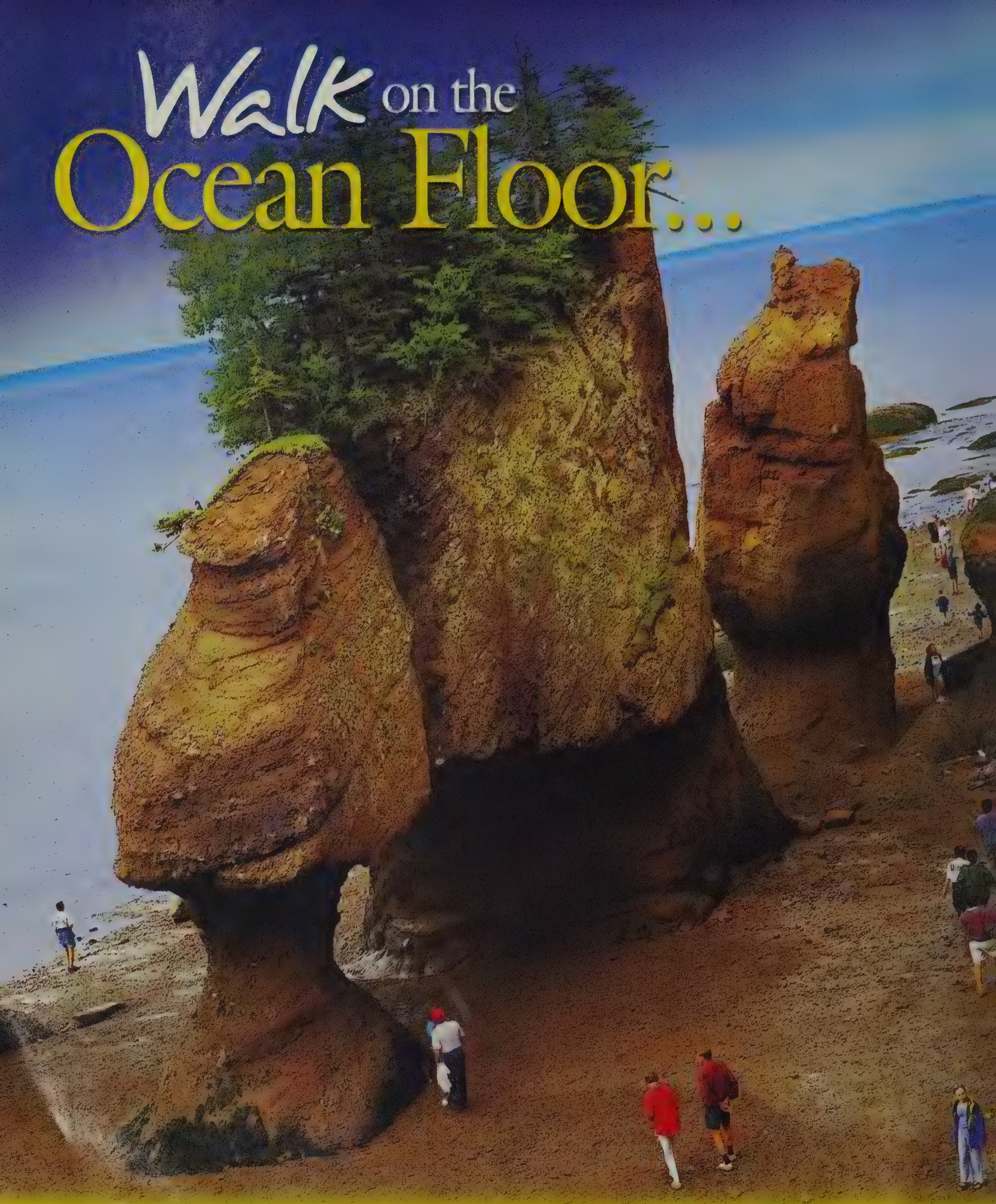
Saint John is known as the Fundy city.





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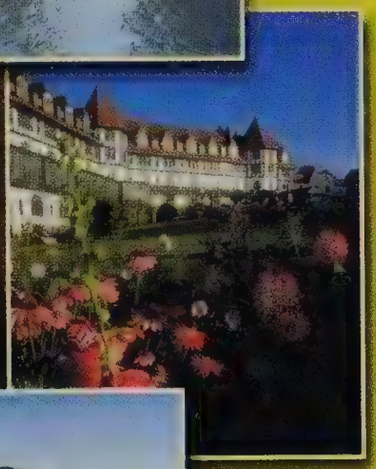

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New York Make a Great Vacation Out of Getting There

New York is one of the most popular vacation destinations for visitors from across the country.

New York has hundreds of golf courses and miles of beaches. The Adirondacks, the state's highest mountains, are a favorite hiking and fishing area.

New York is teeming with scenic byways, from a 150-mile journey along the Hudson River Valley, to a leisurely 340-mile journey through the wineries and waterfalls of the Finger Lake region. You can truly make a vacation out of a single road trip.

The tour of the Hudson River Valley combines the natural beauty of the region with the homes of great Americans. Exit the Thruway (I-87) at Tarrytown. Follow Route 9 north, visiting historic Philipsburg Manor, to Peekskill and Route 6, which takes you along cliffs high above the Hudson River. Cross the Bear Mountain Bridge to Bear Mountain State Park, where you can hike, swim, or enjoy a picnic lunch. Then take Route 9W north to Route 218, which brings you into the village of Highland Falls. Don't miss a tour of the United States Military Academy at West Point.

Return to Route 9W north to Route 218, the Storm King Highway, for a winding drive leading to Storm King Art Center. Rejoin Route 9W through Newburgh, where General George Washington's Headquarters are located, and past several wineries, where you can stop for a tour and a tasting of some of the region's best wines.

Continue north to the Mid-Hudson Bridge (Route 44/55). Crossing the river again, head north on Route 9 to the Franklin D. Roosevelt and the Vanderbilt Mansion National Historic Sites and on to the Village of Rhinebeck. Travel north on Route 9G, and visit Montgomery Place and Olana State Historic Site.

Next turn east into the Taconics, taking Route 23B to Route 23. Take Route 22 south to Millerton. Follow Route 199 through winemaking country to Route 82 to Route 44 to the scenic Taconic Parkway, which leads to the Saw Mill River Parkway and, finally, back to Tarrytown and the Thruway (I-87).

The tour of the Finger Lakes region begins in Elmira, home of the Mark Twain Study and Exhibit; Woodlawn Cemetery, where Mark Twain is buried; and the National Soaring Museum, an impressive exhibition of sail planes and historic gliders.

Travel northeast on Route 13 to Ithaca, the city of waterfalls: dozens are within the city limits and hundreds more are within several miles. Stop and hike at hidden areas, such as Buttermilk Falls. While in Ithaca, don't miss Cornell University.

Follow Route 89 north along the shore of Cayuga Lake and drive to Taughannock Falls State Park, where the state's highest waterfall drops 215 feet into a rock amphitheater. The Cayuga Wine Trail (for more information call 1-800-732-1848) with eight wineries is located along Route 89.

Travel northwest to Geneva. Take Route 14 south along the shore of Seneca Lake—one of the 11 Finger Lakes, known for their deep clear waters. Travel to Dresden and follow Route 54 west to Penn Yan. You are still in wine country, so travel south on Route 54A along the shore of Keuka Lake to Hammondsport. Here are the excellent Glenn H. Curtiss Museum and numerous wineries. Next, drive to Bath on Route 54. Take Route 17 southeast to Corning, where you can explore 3,500 years of glassmaking at the Corning Glass Center.

From Corning, take Route 414 and visit Watkins Glen State Park, with its hiking paths and natural pools formed by the age-old waterfalls tumbling into stone basins. Take Route 14 south to the town of Montour Falls, where you can see Chequaqua Falls and visit Havana Glen Park, with a short scenic walk to Eagle Cliff Falls. Continuing south on Route 414 will take you back to Elmira.

For more information on these travel ideas or the other fabulous cities and great outdoors sites, call **1-800-CALL-NYS**, or visit **www.iloveny.com**.

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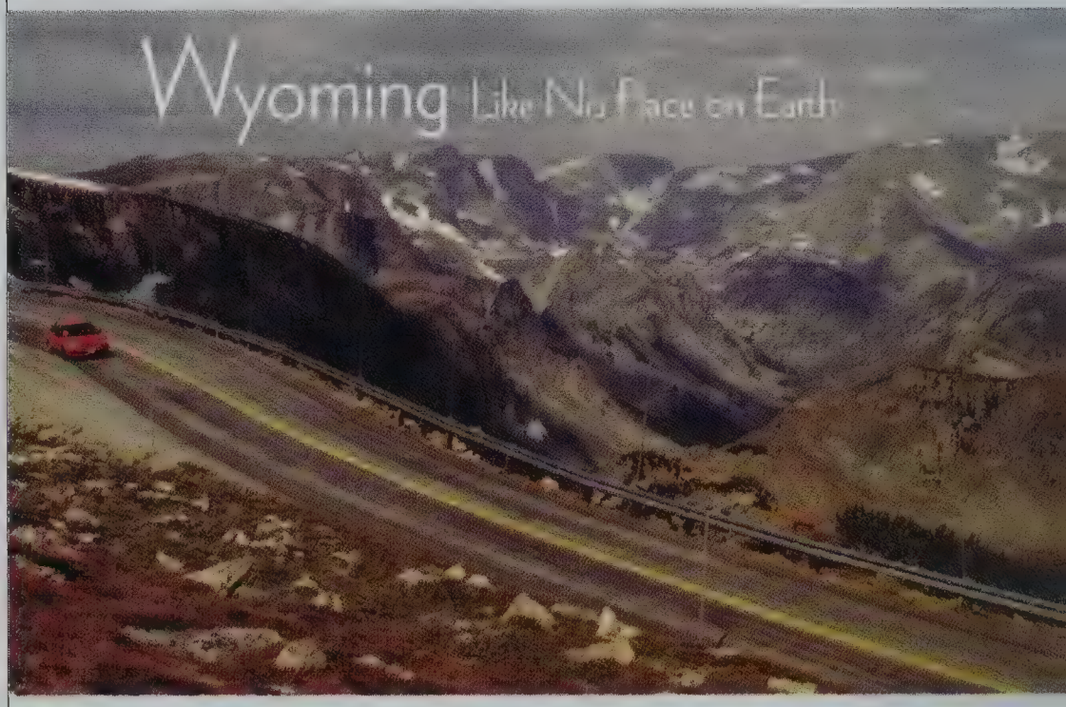
SCENIC BYWAYS



US 212 Beartooth Scenic Byway is just one way to enter the Yellowstone National Park.

As you can imagine, Wyoming has some of the most beautiful and uncrowded scenic byways in the country. Because the state is so large, there is no better way to explore Wyoming's natural wonders than its Scenic Byways. Wyoming's Scenic Byways and Backways Program allows visitors to discover the amazing array of wildlife and scenery in this outstanding state.

These designated travel routes reflect the pride of the Wyoming people who live in the communities and work the ranches along these routes, and are committed to the preservation, protection, and enhancement of these special places. When traveling these roadways, take in the sense of adventure and freedom that first attracted people to this great state and discover why they fully deserve to be recognized with Byway and Backway status.

Three scenic byways cross the Big Horn Mountains in north-central Wyoming, the Cloud Peak Skyway (US 16), the Big Horn Scenic Byway (US 14), and the Medicine Wheel Passage (US 14A). All will get you safely to the other side of the mountains in about the same time.

Big Horn Scenic Byway connects Sheridan and surrounding communities with Greybull, Wyoming and includes 45 miles of scenic mountain driving. Look out over spectacular valley views from one of several roadside turnouts—on a clear day, you can see forever. Interesting stops include Shell Falls, Burgess Junction Visitor Center and Sand Turn.

The Cloud Peak Skyway traverses the southern Big Horn Mountains and offers breathtaking vistas of distant snowcapped peaks along its 45-mile length. This route connects the towns of Buffalo and Tensleep, Wyoming. Highlights include Hospital Hill, Powder Pass, Meadow Lark Lake and Tensleep Canyon.

The Medicine Wheel Passage rises sharply from the Big Horn Basin near Lovell, Wyoming and winds 25 miles through steep canyon terrain and high alpine meadows to Burgess Junction. This route provides primary access to the Medicine Wheel National Historic Landmark. This byway is open only from May to November, and its 10 percent grades may not be the best choice for those pulling trailers or driving a RV.

Of course all of these roads and more lead you on an adventure through the real Wyoming. To learn more about Wyoming's scenic highways and byways, go to the Wyoming web site at **www.wyomingtourism.org**. A new Wyoming Scenic Byways brochure will be available in Spring 2001. To order one, call **1-800-225-5996**.

West Virginia Wild and Wonderful

West Virginia has some beautiful byways from which to enjoy its countryside and history.

THE STATE OF WEST VIRGINIA HAS FOUR NATIONAL scenic byways designated by the FHWA national Scenic Byway Program. These are the Highland Scenic Highway, the Midland Trail, the Coal Heritage Trail, and the Washington Heritage Trail. All preserve the rich culture, heritage and beauty of the state.

The Highland Scenic Highway, a beautiful path through the Monongahela National Forest, takes visitors past mountainous terrain covered by hardwood forests. This scenic byway extends 43 miles from Richwood to US Route 219, seven miles north of Marlinton. The highway follows State Route 39/55 for 21 miles from Richwood to the Cranberry Mountain Visitor Center.

The Coal Heritage Trail winds through mountains and valleys, taking visitors through four of West Virginia's southern counties. As you travel along this byway, you can't help but notice West Virginia's industrial heritage. This area of Appalachia was America's most productive energy-producing region, and its abundant coal fields affected its physical, economic, and social climate.

The Midland Trail follows the same path that Native Americans and pioneers used to head west. The Midland Trail thus takes you on a timeline through colonial America, the Civil War, immigration, African-American history, and the industrial revolution. Before interstates, the Midland Trail was the main route through the West Virginia mountains.

West Virginia boasts having four national scenic byways.

The Washington Heritage Trail loops through three counties of West Virginia's Eastern Panhandle, crossing mountains, farmland, and historic towns. The Eastern Panhandle is significant to historians because George Washington and his family vacationed and built homes in this area. In fact, seven Washington family homes or estates can be seen from the trail.

For more information on West Virginia and its scenic byways, call **1-800-CALL-WVA**, or visit the state's website at **www.state.wv.us/tourism**. ■

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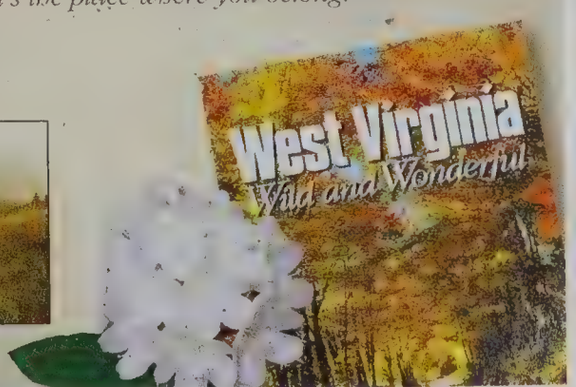

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But there are many more attractions to lure you to this scenic byway. In Warren County you'll drive by parts of the Allegheny National Forest. If you want to stretch your legs, there are 11 campgrounds and 600 miles of trails for hiking. And Crawford County includes the Commonwealth's largest natural lake, and one of the Nature Conservancy's "last great places in the U.S."

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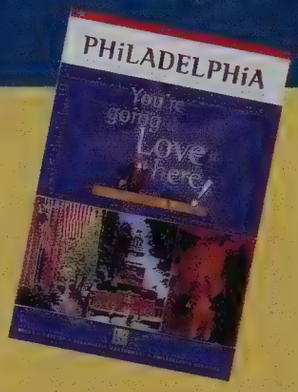

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Swift products are sold and serviced at finer optics, sporting, photo, and specialty stores throughout the world. For more information on Swift Instruments, call **1-617-436-2960**, or visit **www.swift-optics.com**.

To find out more about America's scenic byways, go to National Scenic Byways Online at **www.byways.org**.

This special editorial/advertising supplement was created by the NATURAL HISTORY Special Sections Department and did not involve the magazine's editorial staff. WRITER Stephanie Fekety DESIGN Mindy Phelps Stanton

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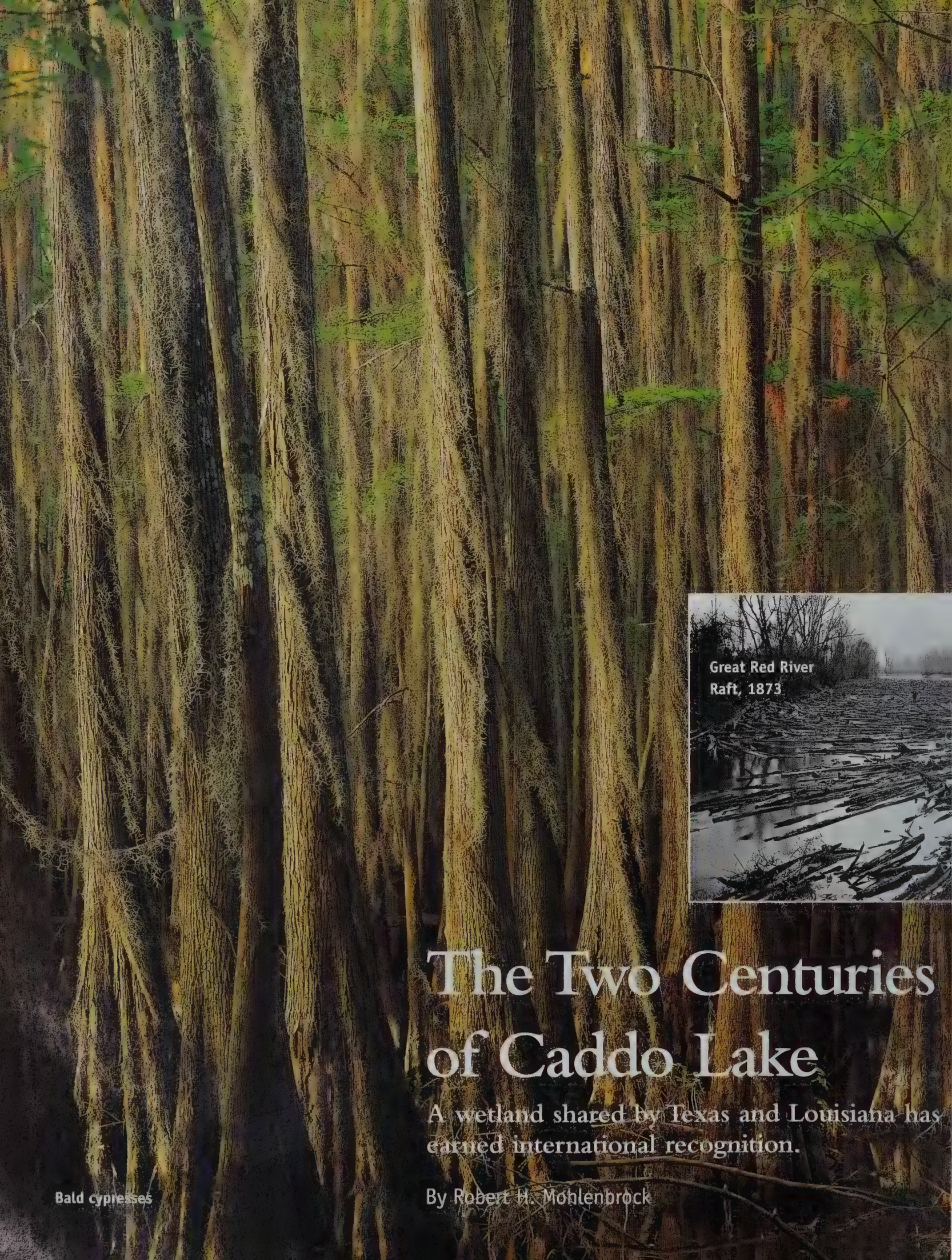


Great Red River Raft, 1873

The Two Centuries of Caddo Lake

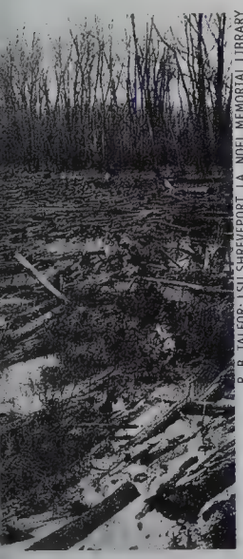
A wetland shared by Texas and Louisiana has earned international recognition.

By Robert H. Mohlenbrock

Bald cypresses

THIS LAND

About 200 years ago, a huge logjam formed in the Red River where it flows through northwestern Louisiana. Because of the buildup of logs, the river spilled into nearby Cypress Valley, creating Caddo Lake, a large body of freshwater that straddles the border between Texas and Louisiana. A legend recounted by the Caddo Indians attributed the lake's origins to an earthquake. In fact, Caddo Lake did develop close in time to the great New Madrid earthquakes of 1811–12, which formed Reelfoot Lake in Tennessee and altered the course of the Mississippi River. Archaeological evidence, however, reveals that Caddo Lake arose earlier, about 1800, and was simply the result of dead trees piling up in what was a relatively slow-flowing, shallow section of the river.



R. B. TALFOR; LSU SHREVEPORT, LA, NOEL MEMORIAL LIBRARY

The logjam, known locally as the Great Red River Raft, persisted and the lake continued to expand until the 1870s, when the federal government cleared the blockage with underwater explosives. This maneuver opened the river to navigation farther upstream and stopped the overflow of water into the lake. During the twentieth century, the lake was dammed for purposes of oil exploration, flood control, and water supply, and it now has a stable water level, with an average depth of eight to ten feet. Altogether, including its associated maze of bayous and cypress swamps, the lake covers fifty square miles. Its diverse habitats may be sampled in Texas's Caddo Lake State Park (established in 1934), whose recreational and camping facilities border Big Cypress Bayou.

In the two centuries since Caddo Lake's formation, plant and animal life have adjusted to its presence. Alligators and water snakes—including venomous water moccasins—are common in and around the lake, which is a haven for several fishes and amphibians that are rare elsewhere in Texas and Louisiana. The lake's large aquatic plants include spatterdock, with yellow, club-shaped flowers; white water lily; and water lotus, with huge creamy flowers and woody fruits. Among its smaller aquatic plants is water shield, whose three-inch-wide, nearly circular leaves are enveloped in a protective coat of gelatinous slime.

Spatterdock

DPA; DEMBINSKY PHOTO ASSOCIATES

In the surrounding region, the terrain consists of low hills whose ridge tops are less than a hundred feet above the elevation of Caddo Lake. Next to the lake, in low-lying areas that often contain standing water year-round, are extensive bald cypress forests. With enlarged, buttressed bases and cone-shaped "knees" to anchor them in their watery habitat, bald cypresses may tower as high as a hundred feet. The knees also store food reserves in the form of starch. When a bald cypress does die and fall into the swampy waters, wildflower seeds become lodged in the decaying wood and sometimes germinate. A fallen log thus often nurtures considerable vegetation, especially species of beggar's-lice.

Bottomland forest grows where the elevation is slightly higher and water stands only some of the time. A still higher zone, which remains free of standing water, supports a mesic (moist) forest. This habitat extends partway up the adjacent slopes, while upland forest occupies the upper slopes and ridge tops.

Caddo Lake is one of only seventeen wetlands in the United States that have been designated Ramsar sites, so named for the Convention on Wetlands, which resulted from a forum that took place in Ramsar, Iran, in 1971. The convention established guidelines for identifying "wetlands of international importance" and ensuring their conservation. More than 120 nations are now contracting parties to the convention. The United States ratified the Ramsar agreement in 1986, and Caddo Lake was listed in 1993, when nearly twelve square miles' worth of Texas-owned land parcels in and around the lake were designated for protection.

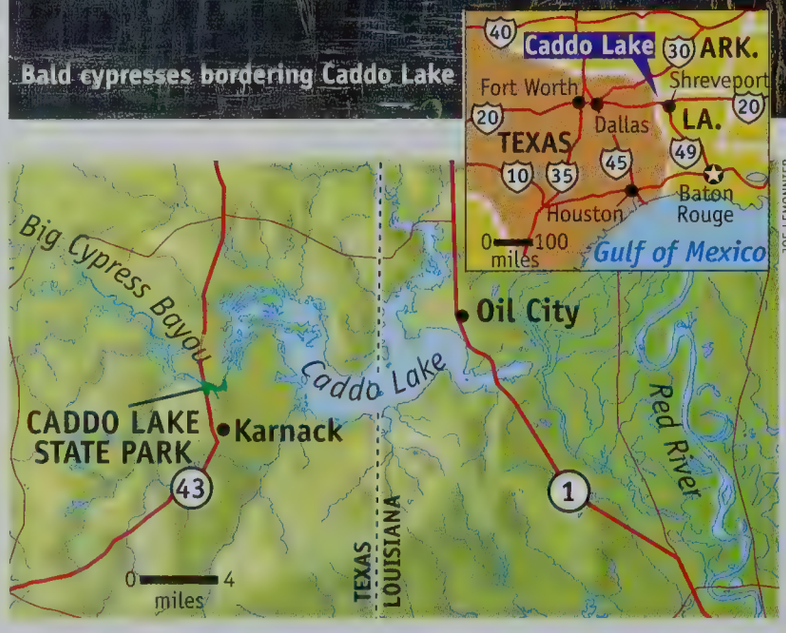
For a wetland to be a Ramsar site, it must do one of the following: (1) contain a representative, rare, or unique example of a wetland type; (2) support endangered species or threatened ecological communities; (3) support populations of plant and/or animal species important for maintaining the biological diversity of a particular region; (4) serve as a refuge for plant and/or animal species or support them at a critical stage in their life cycle; (5) regularly support 20,000 or more waterfowl; (6) regularly support 1 percent of the individuals in a population of one species of waterfowl; (7) support a significant proportion of indigenous fish species; or (8) provide fish stocks with an important spawning ground, nursery, migration path and/or source of food. Caddo Lake meets many of the Ramsar criteria. It is a good example of a bald cypress swamp; it supports a number of plants and animals that are rare for the region; it is home to more than 200 species of birds, 50 of mammals, 90 of reptiles and amphibians, 90 of fishes, and 500 of native plants; and it attracts well over 20,000 waterfowl. Conservation of this ecosystem is the responsibility of the Texas Parks and Wildlife Department and of the U.S. Fish and Wildlife Service and its offices in Texas. In 1999 the protected area was increased to thirty-three square miles.

Robert H. Mohlenbrock, professor emeritus of plant biology at Southern Illinois University, Carbondale, explores the biological and geological highlights of U.S. national forests and other parklands.

For visitor information, contact:
Caddo Lake State Park
RR 2, Box 15
Karnack, TX 75661
(903) 679-3351
www.tpwd.state.tx.us/park/caddo/caddo.htm

LAURENCE PARENT

Bald cypresses bordering Caddo Lake



JOE LEMONNIER

HABITATS

Bald cypress forest contains the largest trees in the area. Growing with the bald cypress are two other species of trees that commonly have buttressed trunks but lack the cypress's "knees"—tupelo gum and pumpkin ash. Other species are water hickory, planer tree, and swamp red maple.

Virginia sweetspire and snowbell bush grow in the shrub layer. These two species, both bearing attractive white flowers, are commonly available from nurseries and garden centers. Plants that colonize fallen tree trunks include two varieties of pink St.-John's-wort, several kinds of beggar's-lice (or stick-tights) with yellowish flower heads, and two stingless members of the nettle family: false nettle and clearweed.

Bottomland forest trees often grow straight and tall, forming a dense canopy in summer and autumn. Common species in the seventy-five-foot range are sweet gum, overcup oak, cherrybark oak, and willow oak. Often growing below these is a secondary canopy of trees from twenty to fifty feet tall. Among them is box elder, a member of the maple family with compound leaves, and green haw, which has two-inch-long curved spines on some or all of its branches and sometimes even on its trunk.

Vegetation on the forest floor in this shaded habitat is often sparse but includes a diversity of species. Among the grasses are the bamboolike giant cane as well as lower-growing wood

FRED HABEGGER; GRANT HEILMAN PHOTOGRAPHY

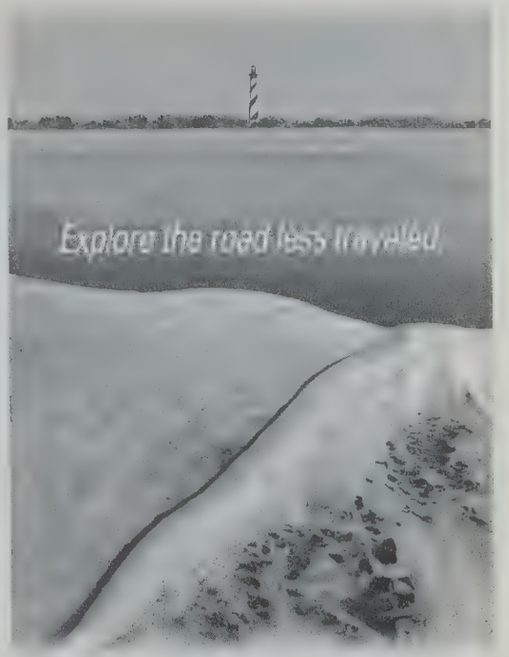
reed grass and white grass. Wildflowers include water horehound, jack-in-the-pulpit, green dragon, and a triangular-leaved blue violet. Here and there are thickets of shrubs such as possum haw, a type of holly that loses its leaves during the autumn. Greenbrier vines and a vine known as supplejack (or rattan vine) climb over some of the vegetation.

Mesic forest tree cover is not as closed as that in bottomland forest. The most common species are water oak, bitternut hickory, and sugarberry (a type of hackberry). Black walnut trees appear in the more elevated tracts. A midcanopy layer is formed by hop hornbeam, musclewood, and pawpaw. Ferns are plentiful, among them rattlesnake fern, named for the tiny spherical spore cases arranged on a special tufted frond. Violets, wild geranium, mayapple, and blue phlox bloom in April and May. After a bit of a summer lull, the blues of woodland asters and the yellows of woodland goldenrods render the forest vibrant in late August.

Upland forest trees include large, sturdy black walnuts and southern red oaks, in addition to the somewhat shorter black gum, red mulberry, redbud, flowering dogwood, and sassafras trees. Here and there is the large-leaved, prickly stemmed Hercules' club, also known as the devil's walking-stick. The brilliant magenta-fruited beautyberry is the most common shrub. Asters, goldenrods, and sunflowers dominate the landscape from late summer to the end of the growing season.

M. C. MILLIGAN

The Outer Banks



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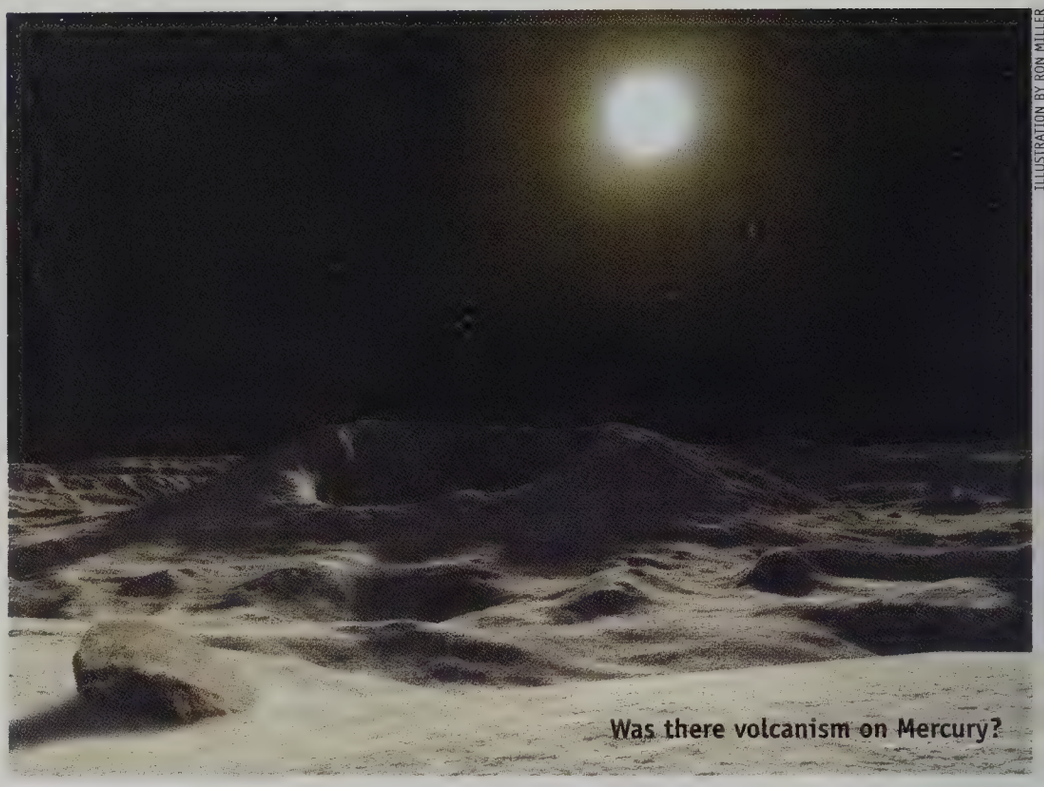


Was there volcanism on Mercury?

ILLUSTRATION BY RON MILLER

The Mysterious Side of Mercury

The *MESSENGER* launch in 2004 promises to lead us out of the dark.

By Richard Panek

The dark side of the Moon? Been there, done that. Another dark side in our solar system, however, is beckoning to some astronomers today, much as the Moon's did to an earlier generation. In this case the dark side is Mercury's, and as always in such discussions, its very existence depends on the definition of "dark."

The dark side of the Moon, for one, *isn't*—dark that is, at least in any day-and-night sense of the word. Every crater on the Moon's surface gets some sun. In fact, during Earth's new Moon phase, it's the Moon's "dark" side that is fully in sunlight.

Still, that side is indeed dark to us, in the sense that we can't see it. As with many major satellites in the solar system, the Moon is in synchronous rotation with its host planet, meaning that it always shows the same face to Earth, never the other. That unseen frontier, perhaps more appropriately termed the far side, proved to be a most tempting target at the dawn of the space age.

Mercury's dark side is now starting to arouse a similar curiosity among astronomers. No, this dark side doesn't actually dwell in darkness either, although until the 1960s most astronomers believed that Mercury was in synchronous rotation with the Sun and that one side of the planet did indeed experience perpetual night. But in terms of what we know about the planet, just about half its surface remains, for all practical purposes, hidden.

Mariner 10 flew past Mercury three times: on March 29 and September 21, 1974, and on March 16, 1975. That's *it*. The photographs that the spacecraft sent back comprise just about the entire database of close or even reliable observations of the surface features of the innermost planet of our solar system—and they cover slightly less than half of Mercury's surface. The other half, though technically visible from Earth or from satellite observatories such as the Hubble Space Telescope, is still pretty much off-limits. The problem is the planet's proximity to the Sun—the same obstacle observers have always had to overcome when studying Mercury. Partly for that reason, observing the planet has historically served more as a means of gathering general astronomical information than as an end in itself. Transits of Mercury (when, from the point of view of an observer on Earth, the planet crosses the surface of the Sun) have been useful, for example, in determining the sizes of the planets relative to the Sun and the overall scale of the solar system (see "Celestial Events," November 1999). And a seeming anomaly in the planet's orbit around the Sun helped substantiate Einstein's general theory of relativity.

But Mercury itself? Consider: Recently when I logged on to Yahoo! and followed the Science topic trail from Astronomy to Solar System to Planets, I found that Mercury had the fewest number of entries among the planets—a mere 4. Even Pluto had double that number, while Mars weighed in with a whopping 143.

Now, however, Mercury's relative anonymity just may be nearing an end. What most surprised astronomers during the *Mariner 10* flybys some twenty-five years ago was the presence of a magnetic field, about 1/100 the strength of Earth's, possibly indicating an active interior. Now researchers revisiting that *Mariner 10* data have found evidence of volcanic activity on the surface of the planet. New radar observations of Mercury's north pole even indicate the possible presence of water in the form of ice.

For these reasons, a NASA mission that was already in the works—the *MESSENGER* (an acronym for Mercury: Surface, Space Environment, Geochemistry, and Ranging) spacecraft, due to launch in 2004 and rendezvous with the planet in 2009—has recently assumed new significance. Unlike *Mariner 10*, *MESSENGER* would map the entire surface of Mercury and, in the process, possibly resolve some questions about planet formation.

In the meantime, observers can continue to content themselves with those infrequent occasions when Mercury ventures far enough from the Sun to provide us with a clear, if fleeting, glimpse. This month, Mercury makes its brightest appearance of the year. Look for it at twilight, trailing the Sun over the horizon in the west-northwestern sky—but look quickly, because the planet will be setting one to two hours after the Sun. By the end of the first week in June, the wash of light from the Sun will render it unobservable, and Mercury will once more be there but not there, dark but not dark, gone but—especially among astronomers—nowhere near forgotten.

Richard Panek is the author of Seeing and Believing: How the Telescope Opened Our Eyes and Minds to the Heavens *(Penguin, 1999).*

THE SKY IN MAY

By Joe Rao

Mercury is just above the west-northwestern horizon at midtwilight, climbing higher night after night. For observers at temperate northern latitudes, mid-May offers the year's best chance to see Mercury. It's at greatest eastern elongation from the Sun (22.5°) on the evening of the 22nd, rendering the "elusive planet" not so elusive at all. The only trick to seeing it is knowing when to look. Mercury will be positioned above and to the right of Saturn on the evening of May 6 and will appear nearly one full magnitude brighter. During the evenings of May 13–17, it rapidly tracks past the brighter Jupiter. A two-day-old crescent Moon sits off to the left of Mercury on the evening of the 24th. Thereafter, the planet dives back down to the horizon, fading rapidly into the sunset.

Venus is a dazzling diamond low in the east at early dawn's light. Technically it reaches its greatest brilliance on May 4 (magnitude -4.5) but will look about the same all month. Venus gains only a little altitude in May, continuing to rise at about the break of dawn. Seen through a telescope, the planet is dwindling in size. At the same time, because of its position vis-à-vis Earth and the Sun, its crescent is thickening. A waning crescent Moon slips well below and to the right of Venus on the morning of the 19th.

Mars, in the constellation Sagittarius, rises at about 11:30 P.M. local daylight time on the 1st but about two hours earlier by month's end, dominating the south-southeastern sky the rest of the night. Mars becomes everyone's object of fascination this month as its golden-orange glow brightens from magnitude -1.1 on May 1 to a dazzling -2.0 by the 31st. From May 13 through August 2, it will in fact surpass Sirius (the brightest of all stars) in brilliance. On May 11 the planet begins retrograde (westward) motion against the backdrop of stars. For observers with telescopes, the brightening Mars is a thrilling, though still challenging, planetary target. The Martian north pole is tilted well toward us this spring as the planet's northern-hemisphere summer draws to an end. Look for the shrinking northern polar ice cap as well as increasingly prominent surface features.

Jupiter is low in the west-northwest during twilight. It is still the brightest "star" at dusk in early May, despite being dimmed by its low altitude and its great distance from Earth (on the opposite side of the solar system). Jupiter has had a brilliant yearlong apparition, but sky watchers are running out of time to view it. The giant planet sets only about fifty minutes after the end of twilight on May 1, and two weeks later it sets with the fading twilight. By the 24th, Jupiter is gone completely, hidden behind the glare of the Sun.

Saturn might be glimpsed very low near the west-northwestern horizon about an hour after sundown during the first week of May. Use the brighter Mercury to guide you to Saturn on the evening of the 6th. For the rest of the month, Saturn lies too close to the Sun to be visible. Saturn's solar conjunction occurs on May 25.

The Moon is full on May 7 at 9:52 A.M. Last quarter comes on May 15 at 6:11 A.M., and the new Moon falls on May 22 at 10:46 P.M. First quarter is on May 29 at 6:09 P.M.

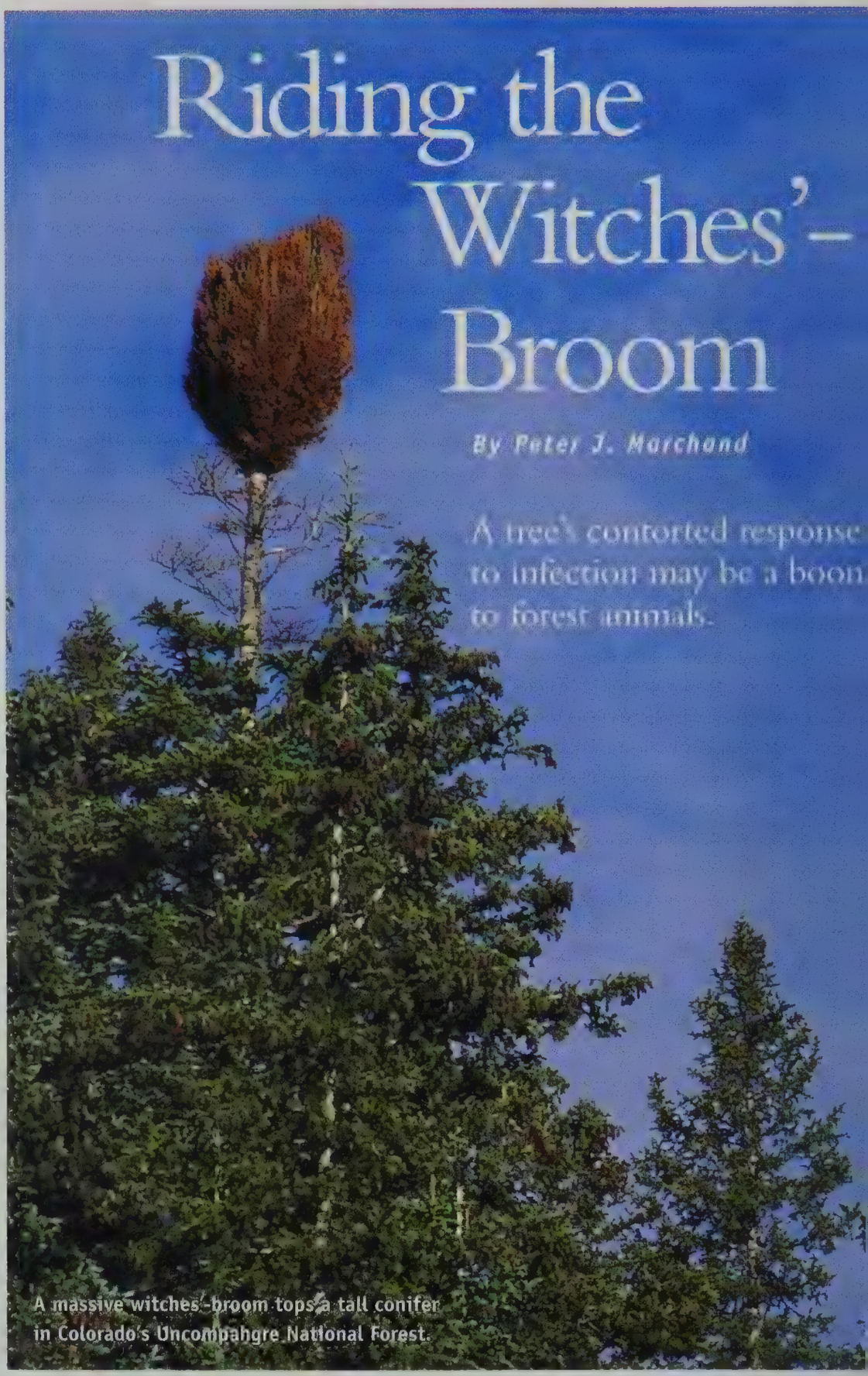
Unless otherwise noted, all times are given in Eastern Daylight Time.

IN THE FIELD

Riding the Witches'-Broom

By Peter J. Marchand

A tree's contorted response to infection may be a boon to forest animals.



A massive witches'-broom tops a tall conifer in Colorado's Uncompahgre National Forest.

I was tagging along with friends on a "hay ride" through Colorado's Arapaho National Forest when the old wrangler at the reins suddenly pulled his team to a halt. Interrupting his nonstop storytelling, he gestured toward a dark shape high in a lodgepole pine and drawled, "Porcupine nest," jerking his head upward in the general direction of the object. My eyes followed his motion to a dense tangle of twigs wedged between the trunk and an oddly twisted branch near the top of the tree. Recognizing the cluster as a large witches'-broom—and having never heard of porcupines nesting in trees—I wondered if this was just local folklore. Or did the old outdoorsman know something about witches'-brooms that I had missed?

Witches'-brooms are odd growths of stunted and closely packed branches. They occur sporadically in many different kinds of trees and shrubs, both broad-leaved and coniferous, and come in all sizes and shapes, from small spindly clusters to large globose masses. Many look like nests. Witches'-brooms result from prolific, localized growth, occasionally induced by genetic mutation but most often caused by parasitic organisms—ranging in size from microscopic to large and luxuriant—that manipulate the plants' own growth hormones.

Among the smallest agents of witches'-brooms are amoeba-shaped phytoplasmas, often no larger than a hundredth of a millimeter in diameter, that infect the phloem, or food-transporting, cells of many broad-leaved trees and shrubs. Though they possess only one-fifth the number of genes found in the typical bacterium, these simple pathogens can wreak havoc within their hosts, redirecting hormones and causing broom formation near branch tips, where plant sugars and nutrients become concentrated.

The most common architects of witches'-brooms in coniferous trees are

certain rust fungi as well as the widespread, and photosynthetic, dwarf mistletoes. Both these organisms cause especially large and convoluted brooming (of the sort the old wrangler had pointed to), and few conifers are immune to their attack. The rusts, spread by tiny spores, induce a dense packing of branches with characteristic yellow foliage that is cast in the fall, though the broom itself keeps growing year-round. Spruce broom rust can infect almost any of the native North American spruces but is found only where the understory shrub bearberry is available as an alternate host (many parasites produce generations that alternate between two different host species, one of which it may not affect adversely). Fir rust produces similar tightly packed brooms in most of the true firs but is limited to areas where chickweed, its alternate host, also grows. By contrast, the forty or so species of New World dwarf mistletoes, collectively distributed from Honduras to the Pacific Northwest and across Canada to New England (with eight more found in the Old World), need no alternate host, and one or another of them attacks almost every coniferous tree species within their range. The sticky seeds of dwarf mistletoe are spread from one tree to another by exploding fruits, often aided by wind or birds; once the seed attaches and grows, it adds its own cluster of shoots to the profusion of abnormal branches promoted by the infection of its host.

Unlike most plant parasites, the broom-forming dwarf mistletoes may considerably benefit a forest community by creating additional food resources and habitat for many animals. A few months ago, I came across a huge, downed Engelmann spruce that held three large witches'-brooms, two of which contained recently occupied red-squirrel nests. One broom, situated close to the trunk about sixty feet above the base, consisted of many contorted branches, some four to five inches in diameter. Together with their dense tangle of twigs, they created a mass exceeding four feet in height. Within this broom was a three-tiered nest system—a veritable squirrel condominium. The floor of the bottom chamber consisted of partially decomposed, densely packed organic duff about two inches thick, overlying a bed of coarse spruce needles. Incorporated into this mass was a considerable amount of grass and animal hair, including a lone crimped guard hair of a deer or elk. Fecal pellets were buried within the floor to a depth exceeding one inch, indicating long usage of the nest.

A parasite that distorts tree growth, dwarf mistletoe (above) is a treat for a porcupine (inset).

Red squirrels are not the only creatures that take advantage of large witches'-brooms—or of the parasites that produce them. Abert's and northern flying squirrels, as well as martens and bushy-tailed wood rats, are known to utilize witches'-brooms for nesting or protection. In addition, ten perching bird and eight raptor species, including Mexican spotted owls and goshawks, sometimes nest within these structures. One raptor, the long-eared owl in eastern Oregon, may be particularly dependent on witches'-brooms for nest sites. But the list of users doesn't end there. The shoots and fruits of dwarf mistletoes are fed upon by at least a dozen species of birds, including many grouse, and also by numerous insects—such as the thicket hairstreak butterfly, whose larvae feed solely on these mistletoes and mimic almost perfectly their color and shape. Add to this twenty-nine or so different fungi known to tap the concentrated resources of witches'-brooms (some parasitizing the mistletoe itself), and the list of species benefiting from the tree-parasite interaction is impressive.

What, then, of the old wrangler's "porcupine nest"? Porcupines feed heavily on the nutritious shoots of dwarf mistletoe, and one researcher has observed porcupines in the Pacific Northwest seeking shelter during winter within some of the larger brooms in Douglas firs. It seems that no end of organisms are ready to jump on the wagon—to ride the witches'-broom, as it were—and share in the spoils of competition between these diminutive parasites and their giant hosts.

Peter J. Marchand is currently a visiting scientist at the Carnegie Museum of Natural History's Powdermill Biological Station in the Allegheny Mountains of western Pennsylvania.

THE EVOLUTIONARY FRONT

Alternative Life Styles

Computer scientists and biologists are finding common ground in the evolution of artificial and natural organisms.

By Carl Zimmer

Do universal laws of evolution exist? There's no bigger question in biology, and none harder to answer. To discover a universal rule, you need more than a single case, and when it comes to life, we're stuck with a data set of one. All life on earth descends from a common ancestor, with every species storing its genetic information in DNA (or, in the case of some viruses, RNA). If scientists someday discover another form of life, perhaps lurking on a moon of Jupiter or in some distant solar system, they may be able to compare its evolution to our own and see if the two histories have followed the same playbook. But such an opportunity may be a long way off.

In 1992 the eminent biologist John Maynard Smith declared that the only way out of this quandary was to build a new form of life ourselves. "We badly need a comparative biology," he wrote. "So far, we have been able to study only one evolving system, and we cannot wait for interstellar flight to provide us with a second. If we want to discover generalizations about evolving systems, we will have to look at artificial ones."

In the nine years since Maynard Smith's call, computer scientists have done their best to answer it. They've tried to create a menagerie of artificial life-forms, from self-replicating software to "intelligent" robots, and they've set off plenty of breathless hype in the process. Some claim, for example, that computer processing speeds are climbing so quickly that within fifty years, robots with superhuman intelligence will be walking among us. Neuroscientists have countered that brains are much more than just masses of neurons: they consist of complex networks that communicate with one another using dozens of chemical signals. Even the simplest of these networks can take decades to decipher. Just figuring out the system of thirty neurons that lobsters use to push food through their stomachs has taken more than thirty years and the collective labor of fifteen research teams. At that rate, millions of years could pass before scientists fully comprehend the workings of the 100 billion neurons that make up the human brain.

But not all is hype and skepticism. Suitably humble experts on artificial life and suitably open-minded biologists are starting to work together. One promising collaboration is being led by Chris Adami, a physicist at the California Institute of Technology; Charles Ofria, a former student of Adami's who is now at Michigan State University; and Richard Lenski, a microbiologist at Michigan State. Building on pioneering work by Tom Ray (now at the University of Oklahoma), Adami and Ofria have created computer programs—digital creatures—that behave in remarkably lifelike ways. And work-

ing with Lenski, they've shown that these creatures, which they call *Digitalia,* evolve much the way biological life-forms do.

Each digitalian consists of a short program that can be run by a computer. The computer moves line by line through the program, methodically executing each command until it reaches the end, whereupon it loops back to the beginning and starts over. A program can reproduce by instructing the computer to make a copy of the program, and this duplicate then starts running on its own.

Adami and his colleagues conceive of the digitalia as organisms living on a two-dimensional plane divided up into thousands of cells. Each digitalian occupies a single cell, and when it reproduces, its offspring take up residence in the adjoining cells. Once a digitalian starts reproducing, its progeny can race across the plane like mold spreading over a slice of bread. (The researchers can watch their progress by means of a graphic display on a computer screen, although the screen itself isn't actually the habitat—there's no one-to-one correspondence between the pixels and the cells.)

Digitalia don't simply replicate; they also evolve. Every time a digitalian replicates, there's a small chance the copy will contain a mutation. Mutations in nature are random changes in a sequence of DNA; in the case of digitalia, mutations consist of certain kinds of random changes in a program. For example, the computer may copy part of a program twice instead of once or may switch one command for another.

As in the real world, most mutations are harmful to digitalia, inserting fatal bugs that prevent them from replicating. Other mutations have little or no effect, building up like junk through the generations. And some help digitalia replicate faster. Those so blessed come to dominate their artificial world, just as natural selection favors well-adapted biological life.

Adami and his associates have found that their digitalia consistently evolve in certain ways—ways that are similar to what biologists see in real life. In one experiment, they created several different strains of digitalia and let them evolve. They found that these programs consistently shrank down to sleek, short sequences of commands—as few as eleven command lines in some cases—that carried the minimum amount of information necessary for replicating. It takes less time to copy a short program than a long one, so the shorter the program, the more quickly it can multiply.

In the 1960s Sam Spiegelman and his colleagues at the University of Illinois got a similar result when they studied the evolution of RNA viruses. They put viruses into a beaker and supplied them with all the enzymes they needed to replicate. Twenty minutes later, the researchers transferred some of the newly replicated viruses to a new beaker and let them replicate again. After a few rounds, the scientists waited only fifteen minutes each time, and then only ten minutes, and finally only five. By the end of the experiment, the viral RNA had shrunk to 17 percent of its initial size. The viruses evolved into such small versions of themselves because they could shed genes they had used to invade and commandeer host cells. These had become unnecessary and now only slowed down the RNA's replication. As with digitalia, the most successful viruses under these conditions were the simplest.

Normally, however, life doesn't exist in a test tube, with all its needs taken care of by a technician. Organisms have to eat, or photosynthesize, or somehow consume the energy and matter around them. To make digitalia more lifelike, Adami and his colleagues require them to eat to survive. Numbers are their food.

Each organism is supplied with a random sequence of 1's and 0's. Just as some bacteria eat sugar and transform it into useful proteins, digitalia are required to read these numbers and transform them into meaningful outputs. With the right combinations of commands, for instance, they can determine whether three numbers in a row are identical, or they can turn a string of numbers into its opposite ("10101" becoming "01010"). The scientists reward the digitalia for evolving the ability to do these tasks. The programs of these lucky organisms start running faster, and as a result, they multiply faster. Soon their numbers overwhelm the less capable digitalia.

Under these complex conditions, the digitalia don't turn into stripped-down creatures. Instead, they evolve from simple replicators into sophisticated data processors that can crunch numbers in complicated ways. Human programmers, of course, can also write programs to carry out these tasks, but sometimes the digitalia evolve versions that are unlike anything ever conceived by a human designer.

To discover a universal rule, you need more than a single case. With life, we're stuck (so far) with a data set of one.

Someday this sort of evolution may produce new kinds of efficient, crash-proof software. But Adami and Ofria are not interested in the commercial possibilities of digitalia; they're too busy working with Richard Lenski, comparing their artificial life to biological life.

The partnership began after Lenski heard Adami give a talk about his digitalia. Adami showed the audience a graph charting the creatures' replication rate. The line on the graph rose for a while before reaching a plateau and then rose to still higher plateaus in a series of sudden jerks. Lenski was aston-

ished. He and his colleagues had observed how *Escherichia coli* bacteria evolved over thousands of generations, acquiring mutations that helped them consume sugar more efficiently and reproduce faster. When Lenski had charted their evolution, he had found the same punctuated pattern that Adami identified. Digitalia and *E. coli* apparently had some profound things in common. The two teams of scientists joined forces in 1998.

Since then, they have found more similarities between digitalia and biological organisms. In 1995 Lenski and a student, Mike Travisano, ran an experiment to gauge the importance of chance, history, and adaptation to the evolution of bacteria. From a single *E. coli* they cloned twelve populations, which they regularly supplied with the simple sugar glucose. Over the course of 2,000 generations, all the colonies evolved, becoming better and better adapted to the glucose diet. Then Lenski's team switched the bacteria to a diet of a different sugar, maltose. Over the course of another 1,000 generations, the colonies adapted until they could grow almost as well on their new food.

But the evolution of the colonies was not just a simple story of adapting to food. Lenski and his colleagues also kept track of the size of the microbes as they adapted. Originally the colonies were identical, but by the time the scientists switched them from glucose to maltose, they had diverged into a range of different sizes. Then, as the bacteria adapted to their new diet, their size changed again. Some colonies changed from big to small, others from small to big. Overall, the researchers found, the bacteria's adaptation to their diet had nothing to do with their size change. Chance mutations could alter cell size with little effect on their fitness, that is, their success in survival and replication.

Adami and a student, Daniel Wagenaar, recently converted Lenski's experiment into one they could run with their computer creatures. They created eight copies of a single program, which they used to seed eight separate digitalia colonies. The organisms were rewarded for mastering a set of logical operations, but once they had become well adapted, the researchers changed the reward system so that an entirely different set of operations was favored—a digital version of switching from glucose to maltose.

Adami and Wagenaar observed that digitalia could evolve quickly and thrive in new conditions, just as *E. coli* had. They also monitored the length of the programs—a trait that proved relatively unimportant to their fitness, just as cell size was for the bacteria. Adami and Wagenaar found that the evolution of a program's length was determined mainly by its history and by chance mutations, rather than by the pressure to adapt.

You can create billions of digital organisms and watch them evolve for thousands of generations in a few hours.

These parallel experiments suggest, once again, that artificial and biological life evolve according to at least some of the same rules. When it comes to traits that experience intense natural selection—such as the mechanisms for finding food or crunching numbers—the end results may erase much of a trait's previous history. But in the case of traits that experience only weak selection—such as the size of a bacterium or the length of a computer program—chance mutations can send evolution off in unpredictable directions, and their effects can linger for a long time as historical vestiges.

One of the great attractions of digitalia is that they're so much easier to work with than biological life. You can create billions of different digitalia strains and watch them evolve for thousands of generations in a matter of hours. And every step of that complicated journey is preserved on a computer, instantly available for study—making it possible to ask questions about digitalia that can't be addressed in ordinary experiments.

For example, biological evolution has produced structures and organisms of awesome complexity, from termite colonies to the human brain. But does this mean that evolution has been dominated by a steady trend of rising complexity over time? A long line of thinkers have claimed that it does; one recent example is Robert Wright, in his book *Nonzero: The Logic of Human Destiny*. Stephen Jay Gould, on the other hand, has argued that what some people may interpret as an overall trend toward complexity is really the random rise and fall of complexity in different branches of the tree of life.

Though fascinating, this debate has stalled because scientists have yet to settle on a definition of complexity in biology or on a way to measure its change. Complexity is not unique to biology, however. Mathematicians have found precise ways to measure the complexity of information, whether it's a picture of Jupiter transmitted by the *Galileo* probe or the sound of a friend's voice on the telephone. Since digitalia genomes are strings of commands—in other words, information—Adami and his associates have been able to adapt mathematical methods to measure digitalia complexity as well.

To gauge how much of the information in a digitalia program is vital to the organism's survival, the researchers mutate each command in the program in every possible way and then see whether the organism can still function. A program may be stuffed with useless commands and turn out to be quite simple; even if you tamper with a lot of its code, it will still function. But another program of the same length

may turn out to be complex, using most of its commands in precise ways that don't tolerate much tinkering.

Following this method, Adami and his coworkers have measured the complexity of digitalia colonies as they've evolved through 10,000 generations. Overall, the complexity consistently rises until it levels off. Its ascent is jagged but is an ascent nevertheless. For digitalia, at least, evolution does have an arrow pointing toward greater complexity.

As interesting as these results are, any application to biological life comes with some important caveats. For one thing, the scientists only measured the information that was contained in the digitalia programs, which is akin to biologists measuring the complexity of information encoded in a genome. There's no simple equation that enables a biologist to use genetic complexity to calculate the complexity of the things a genome creates.

Another caveat to bear in mind is that the complexity of digitalia increases in a fixed environment—that is, the rewards for processing data don't change. In the natural world, conditions are always changing, with an endless flow of droughts, floods, outbreaks of disease, and other life-altering events. Every time conditions change, genes that were specialized to deal with the old conditions become useless. The obsolete genes may mutate or even disappear, and in the process, the complexity of a species' genome dwindles. Only as the species adapts to new conditions may complexity increase again.

In the natural world, the arrow of complexity may get turned back too often to have any significant effect on long-term evolution. But just finding that arrow is an admirable start. Indeed, everything about digitalia is, at the moment, a start—the start of a new kind of science and just maybe the start of a new kind of life.

Science writer Carl Zimmer is the author of At the Water's Edge *and* Parasite Rex.

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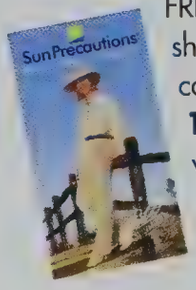

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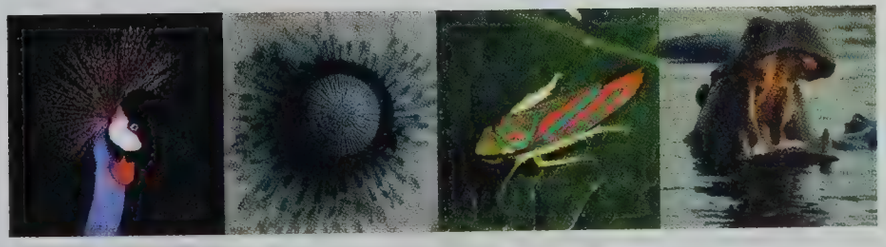

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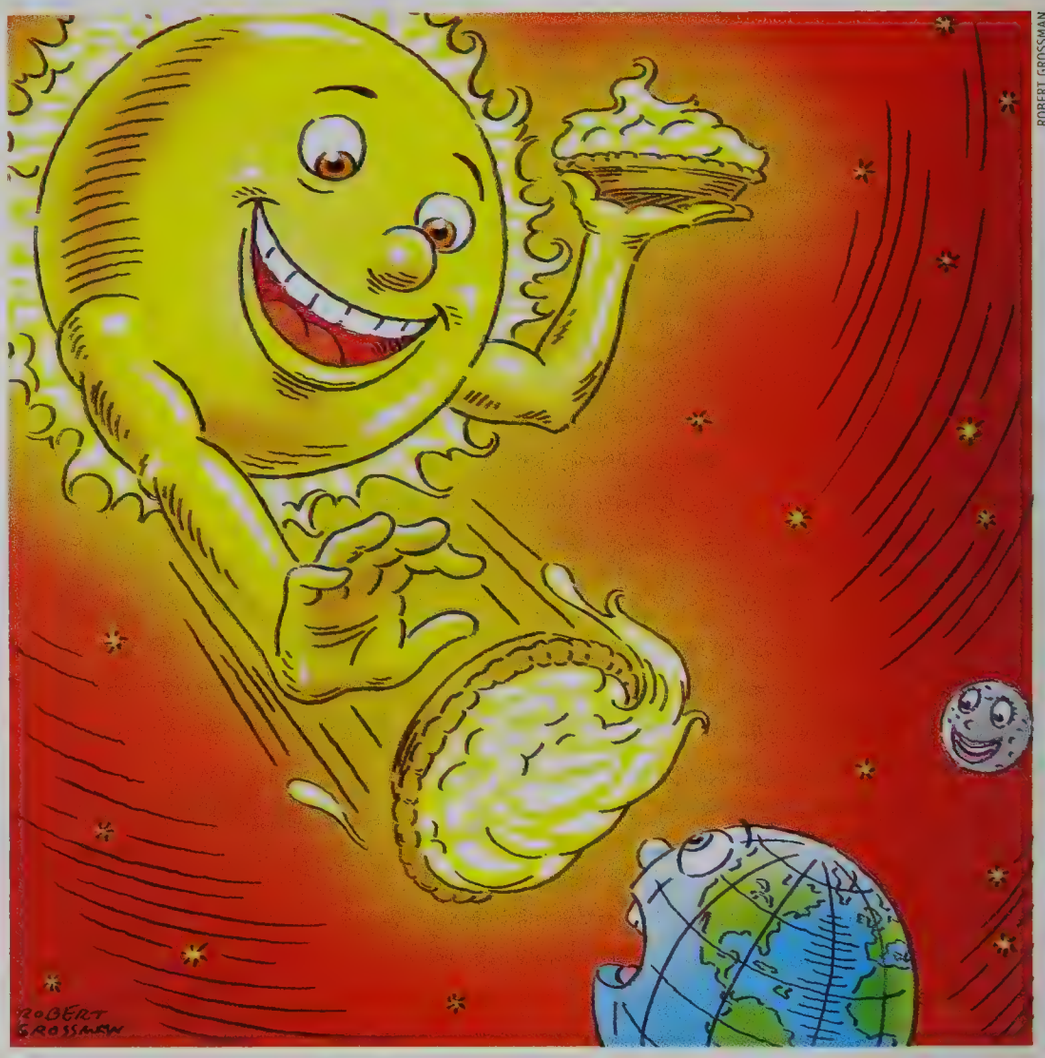


ROBERT GROSSMAN

Cosmic Plasma

There's a lot of it out there but, thankfully, not too much of it down here.

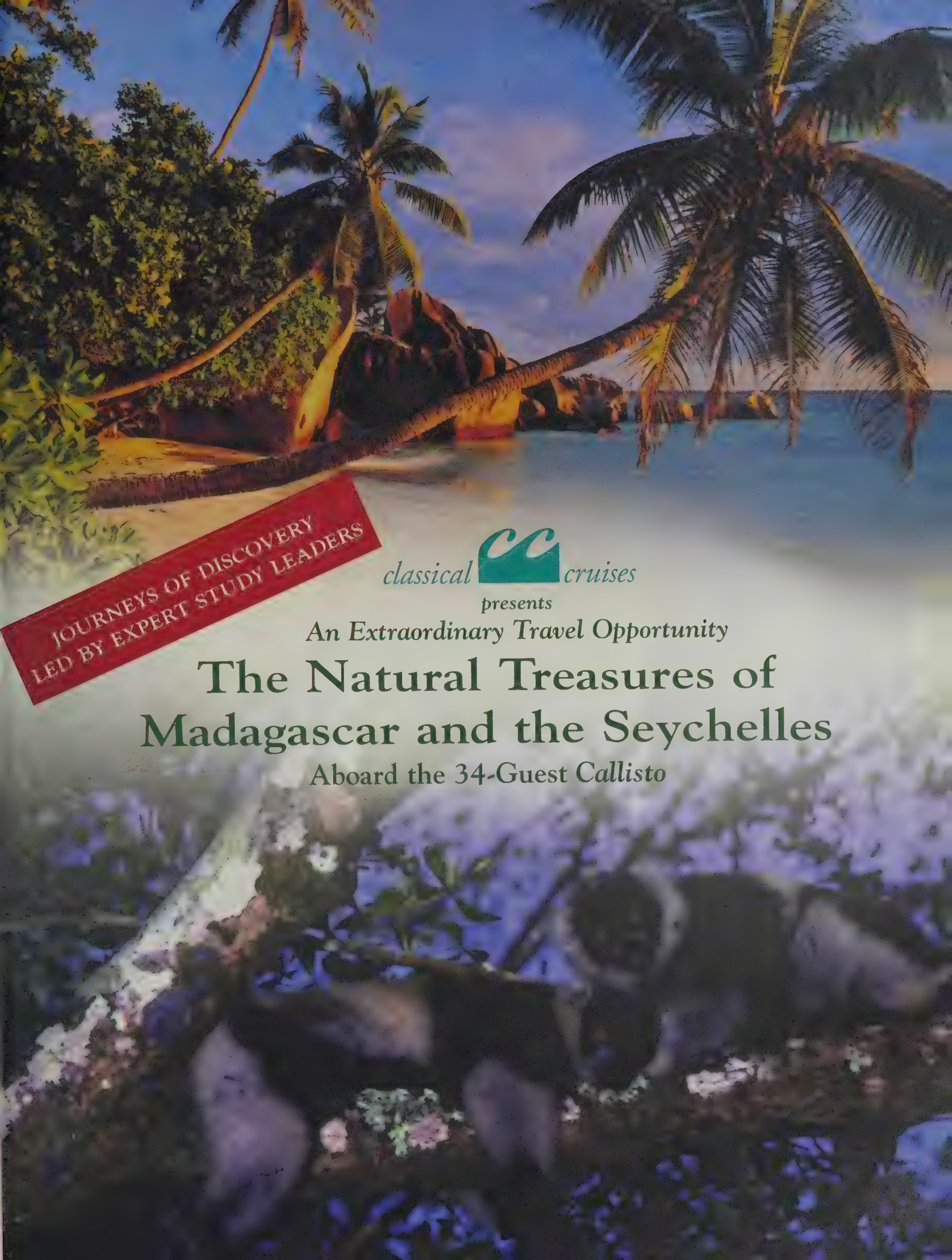
By Neil de Grasse Tyson

Only rarely does the medical doctor's vocabulary overlap with that of the astrophysicist. The human skull has two "orbits," the round cavities where your two eyeballs go; your "solar" plexus sits in the middle of your chest; and your eyes, of course, have "lenses"—though our bodies contain no quasars and no galaxies. For orbits and lenses, the medical and astrophysical usages resemble each other greatly; on the other hand, the term "plasma" is common to both disciplines, yet the two meanings have nothing whatever to do with each other. A transfusion of blood plasma can save your life, but a brief encounter with a glowing blob of million-degree plasma would leave a puff of smoke where you had just been standing.

Astrophysical plasmas are remarkable for their ubiquity, yet they're hardly ever discussed in introductory textbooks or in the press. Writers of science books often call plasmas the fourth state of matter because of a panoply of properties that sets them apart from the familiar solids, liquids, and gases. A plasma has freely moving particles, just as a gas does, but a plasma can conduct electricity as well as interact strongly with magnetic fields passing near it or through it. Atoms within a plasma have had some or all of their electrons stripped from them by one mechanism or another. And the combination of high temperature and low density in a plasma only occasionally allows electrons to recombine with their host atoms. Taken as a whole, the plasma remains electrically neutral, because the total number of electrons (which are negatively charged) equals the total number of protons (which are positively charged). But a plasma can seethe with electric currents and magnetic fields, so in many ways, it behaves nothing like the ideal gas we all learned about in high-school chemistry class.

The effects that electric and magnetic fields have on matter almost always dwarf the effects of gravity. The electrical attraction between a proton and an electron is forty powers of ten stronger than their gravitational attraction. So strong are electromagnetic forces that a child's magnet easily lifts a paper clip off a tabletop, despite Earth's formidable gravitational tug. Want a more interesting example? If you managed to extricate all the electrons from a cubic millimeter of atoms in the nose of a space shuttle and if you attached those electrons to the base of the launch pad, then the attractive force would inhibit the launch. All engines would fire, but the shuttle wouldn't budge. And if the Apollo astronauts had brought back to Earth all the electrons from a 100-inch cube of lunar dust (leaving behind the atoms from which they came), the force of attrac-

(Please turn to page 47)



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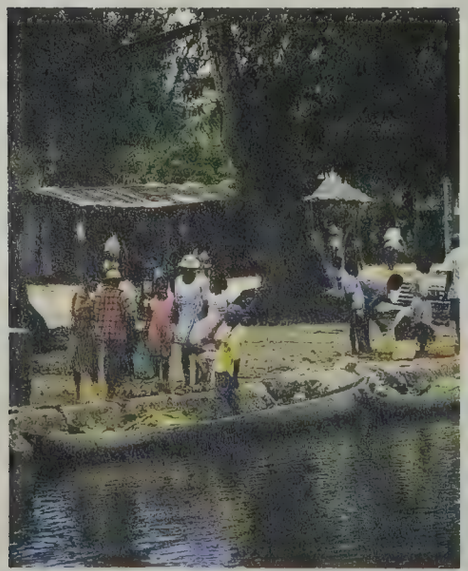
Aboard the 34-Guest *Callisto*

Mahe, Seychelles

Chameleon; Nosy Mangabe Reserve, Madagascar



Maroantsetra, Madagascar

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HIDDEN AWAY IN THE INDIAN OCEAN, spread out over a vast expanse of sea, lies an incredible natural paradise, the islands of Madagascar and the Seychelles. Here Nature has developed a magical garden of rare plants and flowers and filled it with strange and wonderful wildlife. This winter, Classical Cruises invites you to discover the natural treasures of this remarkable island world with some of the world's leading naturalists and conservationists.

Created and preserved by continental shifts that occurred millions of years ago, the Seychelles and Madagascar are an ecological wonderland, filled with unique species of animals, birds, and plants. Here you'll find an array of unusual wildlife, including the Seychelles sunbird, the blue-barred parrotfish, the giant land tortoise, and more than 30 species of lemurs. You'll also encounter rare habitats, including the primeval rainforests in the high hills of Mahe and Silhouette, where tall and strangely twisted trees are festooned with tiny native begonias and miniature orchids and pitcher plants cling to the gnarled trunks.

On these voyages, as with every Classical Cruises program, we have engaged distinguished Study Leaders to introduce you to the natural wonders of the region. Explore the evolutionary history of the islands with renowned paleoanthropologist Dr. Donald Johanson and discover the extraordinary birdlife of the region with Dr. Donald F. Bruning, Curator and Chairman of Ornithology at the Wildlife Conservation Society. Examine the conservation issues affecting the area with prominent wildlife expert Joan Embery and noted ABC News correspondent Lynn Sherr.

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Study Leaders

LYNN SHERR

Departure: *December 20 - January 7*

Award-winning ABC News correspondent Lynn Sherr has covered a wide range of stories and investigative reports in her journalism career, but it was a 1973 visit to Africa that led to her intense interest in giraffes. In her book *Tall Blondes*, Sherr chronicles the giraffe's cultural history as well as its links with science, geography, literature, art, and most importantly, conservation.

DR. DONALD C. JOHANSON

Departure: *January 15 - February 3*

A pioneer in the field of physical anthropology, Dr. Donald C. Johanson profoundly influenced the understanding of early hominid evolution with his discovery of the "Lucy" skeleton in Ethiopia in 1974. The author of numerous books, most recently *From Lucy to Language*, Dr. Johanson narrated the popular PBS/Nova series "In Search of Human Origins" and served as curator of physical anthropology at the Cleveland Museum of Natural History for many years.

JOAN EMBERY

Departure: *January 29 - February 17*

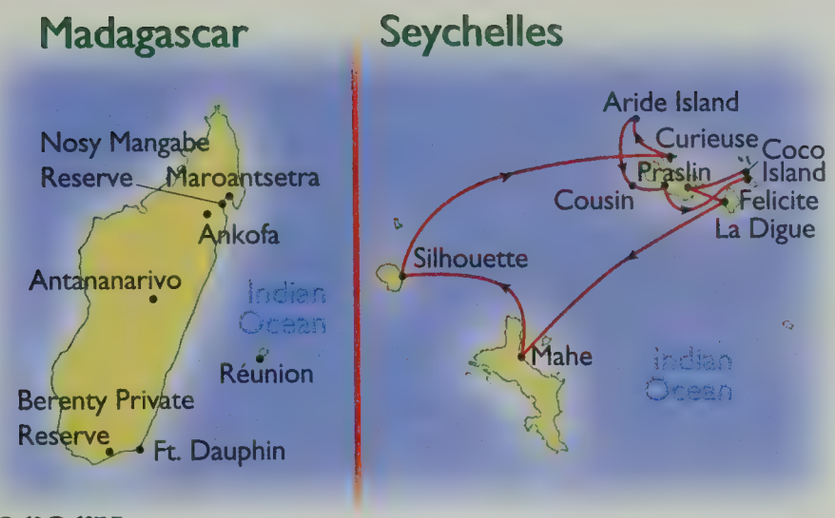
Nationally known for her appearances on late-night television with Johnny Carson, renowned conservationist and animal expert Joan Embery is dedicated to the preservation and understanding of the Earth's wildlife and habitats. Embery serves as Conservation Ambassador for the San Diego Zoo and the San Diego Wild Animal Park and in that role, captivates and inspires the public with her message of wildlife preservation. She is also the proud caretaker of a lemur.

DR. DONALD F. BRUNING

Departure: *February 12 - March 3*

Dr. Donald F. Bruning is curator and chairman of Ornithology at the Wildlife Conservation Society in New York. A distinguished birder, he is actively involved in conservation efforts worldwide.

Other departures available.
Please inquire with Classical Cruises.



Itinerary

Day 1
DEPART USA

Day 2
EUROPEAN CITY
Transfer to an airport hotel until the evening flight to Madagascar.

Day 3
ANTANANARIVO, MADAGASCAR
Morning arrival in Antananarivo. Transfer to the *Hotel Colbert*.

Days 4 & 5
ANTANANARIVO | FT. DAUPHIN | BERENTY PRIVATE RESERVE
On the morning of Day 4, fly to Ft. Dauphin. Transfer to the Berenty Private Reserve, on the banks of the Mandrare River. Found here are 115 plant species, 83 bird species, and several species of mammals, most prominently lemurs. Accommodations are at the *Gite d'Etape*.

Day 6
BERENTY PRIVATE RESERVE | FT. DAUPHIN | ANTANANARIVO
Fly from Ft. Dauphin to Antananarivo. Upon arrival, visit Ambohimanga, the old capital of the Merina royal family. Continue to Antananarivo and the *Hotel Colbert*.

Day 7
ANTANANARIVO | MAROANTSETRA
Morning flight to Maroantsetra. Travel to Andrifotra Private Reserve, created to protect the region's wildlife. Accommodations at *Relais du Masoala*.

Day 8
NOSY MANGABE RESERVE
Spend the day at Nosy Mangabe Reserve, home to the endangered aye-aye lemur, black-and-white, ruffed, and brown lemurs; and several species of chameleon.

Day 9
ANKOFA
This morning, cruise up the Antainambalana River by pirogue to Ankofa, where we experience the daily life of a typical Malagasy village.

Noddy Tern; Cousin, Seychelles

Day 10
MAROANTSETRA | ANTANANARIVO
Transfer to Maroantsetra's airport for the flight to Antananarivo. Transfer to the *Hotel Colbert*.

Day 11
ANTANANARIVO | RÉUNION
Tour Antananarivo, then fly to Réunion. Overnight at the *Hotel Meridien*.

Day 12
MAHE | EMBARKATION
Morning flight to Mahe, the main island in the Seychelles. Embark *Callisto*. Overnight aboard ship in Mahe.

Day 13
SILHOUETTE ISLAND AND CURIEUSE BAY
A hike through the pristine rain forest on Silhouette Island reveals several species of endemic orchids, bwa sandal, bwa rouz, kapisen, and other trees.

Day 14
CURIEUSE AND ARIDE ISLANDS
Visit Curieuse, home to giant land tortoises, the coco de mer, and several bird species. Afternoon at Aride, whose plant life includes the beautiful cream and magenta Wright's Gardenia and the recently discovered Aride Peponium, found nowhere else on earth.

Day 15
COUSIN ISLAND AND ANSE LAZIO, PRASLIN
Morning at uninhabited Cousin, home to Seychelles warblers, wedge-tailed shearwaters, fairy terns, lesser noddies, and others. Then sail to Praslin's Anse Lazio for swimming, snorkeling, and relaxing.

Day 16
FELICITE AND COCO ISLANDS
Morning at Felicite, covered with a profusion of palms and other plants. Afternoon swimming and snorkeling at tiny Coco isle.

Day 17
PRASLIN ISLAND
Explore the Vallee de Mai, believed by some to be the Garden of Eden. Watch for the Seychelles black parrot; the Seychelles blue pigeon; sunbirds; and Seychelles flying foxes.

Day 18
LA DIGUE
Call at La Digue for a tour of the forested nature reserve and a swim at Anse Source d'Argent. In the evening, dock in Mahe.

Day 19
MAHE | DISEMBARKATION
Disembark at Mahe for a tour of the island. Relax at the *Hotel Plantation* before the evening flight.

Day 20
EUROPEAN CITY | USA
Arrive in a European city to connect with the return flight to the USA.

Departures

Depart	Return
December 20, 2001	January 7, 2002 *
January 15, 2002	February 3, 2002
January 29, 2002	February 17, 2002
February 12, 2002	March 3, 2002

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* The Madagascar portion follows the cruise on this departure.

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- Seven-night Seychelles cruise aboard *Callisto*, with accommodations in an outside cabin with marble-appointed private bathroom.
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- House wine and soft drinks with lunch and dinner aboard ship.
- Welcome and farewell receptions aboard ship, hosted by the captain.
- Educational program of lectures and discussions provided by an accompanying study leader.
- Complete program of tours as described, including all shore excursions.
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The New 34-Guest *Callisto*

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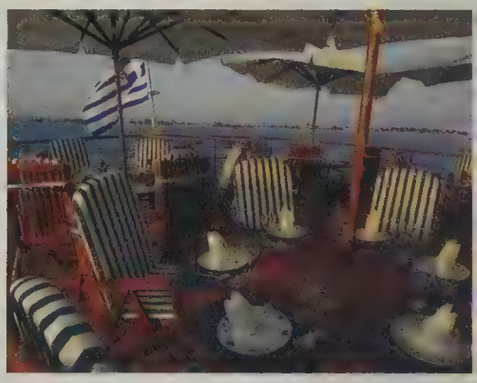
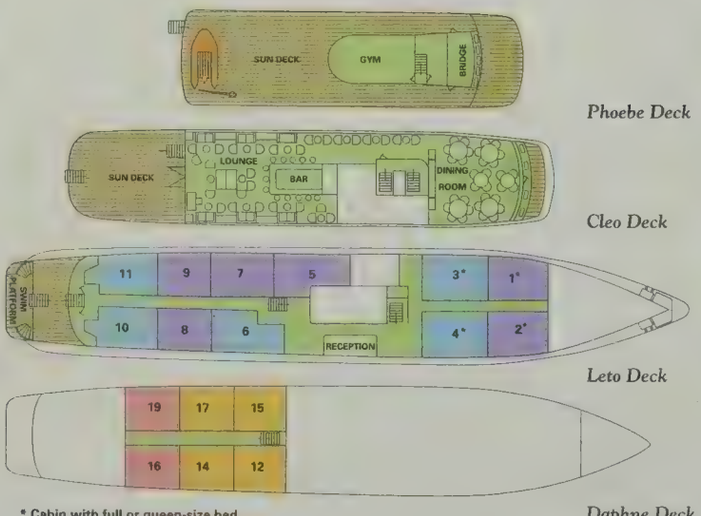
Lounge



Dining alfresco

Deck Plan



* Cabin with full or queen-size bed

Gym

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Per Person, Double Occupancy

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Rate	$8,195	$8,595	$9,095	$9,495

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(Continued from page 46)
tion would exceed the gravitational attraction between Earth and the Moon.

Earth's most conspicuous plasmas are lightning, the trail of a shooting star, and the ordinary electric shock you get after shuffling around on your living-room carpet in your wool socks and then touching a doorknob. Electrical discharges are jagged columns of electrons that abruptly move through the air when too many collect in one place. Lightning, for instance, happens to strike Earth's surface thousands of times per hour. The centimeter-wide air column through which a bolt of lightning travels is turned into glowing plasma in a fraction of a second, having been raised to a temperature ten times that of the Sun's surface by these flowing electrons.

Every shooting star is a tiny particle of interplanetary debris moving so fast that it burns up in the air and descends to Earth as harmless cosmic dust. Almost the same thing happens to a spacecraft that reenters our atmosphere. Since its occupants don't want to land at the near-Earth orbital speed of 18,000 miles per hour (about five miles per second), the craft must slow down and its kinetic energy must go somewhere. Shock waves along the leading edge heat the craft during reentry. The heat is rapidly whisked away by protective shields. This is why the astronauts, unlike shooting stars, do not descend to Earth as dust. For several minutes during a descent, the heat is so intense that every molecule surrounding the space capsule becomes ionized, cloaking the astronauts in a temporary plasma barrier that none of our communication signals can penetrate. This is the infamous blackout period, when the craft is aglow and Mission Control knows nothing of the astronauts' well-being. The craft continues to slow down as it plows through the atmosphere. Along the way, the temperature drops, the air gets denser, and the plasma state can no longer be sustained. The electrons go back home to their atoms, and communication is quickly restored.

While relatively rare on Earth, plasmas comprise more than 99.99 percent of all the visible matter in the cosmos. This tally includes every glowing star and "gas" cloud. Nearly all the Hubble Space Telescope's beautiful photographs of nebulae in our galaxy depict colorful gas clouds in the form of plasma. The shape and density of some of these clouds are strongly influenced by the presence of magnetic fields from nearby sources such as pulsars. The plasma can lock a magnetic field into place and torque or otherwise shape the field to its whims.

Earth's most conspicuous plasma? Try lightning, or the trail of a shooting star.

This marriage of plasma and magnetic field is a major feature of the Sun's eleven-year cycle of activity. The plasma near the Sun's equator rotates slightly faster than the plasma near its poles. This differential is bad news for the Sun's complexion. With the Sun's magnetic field "frozen" into its plasma, the field gets stretched and twisted. Sunspots, flares, prominences, and other solar blemishes come and go as the gnarly magnetic field punches through the Sun's surface, carrying solar plasma along with it.

Because of all this hubbub, the Sun flings charged particles into space, up to a million tons of them per second—including electrons, protons, and bare helium nuclei. The resultant particle stream, sometimes a gale and sometimes a zephyr, is more commonly known as the solar wind. This most famous of plasmas ensures that comet tails point away from the Sun, no matter whether the comet is coming or going. By colliding with molecules in Earth's atmosphere near our magnetic poles, the solar wind is also the direct cause of the aurora borealis and aurora australis (the northern and southern lights), not only on Earth but on all planets with atmospheres and strong magnetic fields.

Depending on a plasma's temperature and its mix of atoms, some free electrons will recombine with needy atoms and cascade down the myriad energy levels within. En route, the electrons emit light in prescribed wavelengths. The auroras owe their beautiful colors to these electron hijinks, as do neon tubes, fluorescent lights, and those glowing plasma spheres offered for sale next to the lava lamps in tacky gift shops.

These days, satellite observatories give us an unprecedented capacity to monitor the Sun and report on the solar wind as though it was part of the day's weather forecast. My first-ever televised interview for the evening news was triggered by the report of a plasma pie hurled by the Sun, at 300 miles per second, directly at Earth. Everybody (or at least the reporters) was scared that bad things would happen to civilization when it hit. Severe plasma ejections can fry the circuits on satellites and knock out transformers at power stations. But this one was mild and innocent. I told the viewers not to worry—that Earth's magnetic field protects us—and I invited them to use the occasion to go north and enjoy the aurora that the solar wind would cause.

The Sun's rarefied corona, visible during total solar eclipses as a glowing halo around the silhouetted Moon, forms a five-million-degree plasma that is the outermost part of the solar atmosphere. With temperatures that high, the corona is the principal source of the Sun's X rays. Without the benefit of an eclipse to block the Sun's bright surface, the corona easily gets lost in the glare.

There's an entire layer of Earth's atmosphere where electrons have been kicked out of their host atoms by ultraviolet light from the Sun, creating a plasma blanket called the ionosphere. This layer reflects certain frequencies of radio waves, including those of the AM dial (which can reach hundreds of miles) and of shortwave (which can reach thousands of miles beyond the horizon). FM signals and those of broadcast television, however, pass right through the ionosphere, traveling out to space at the speed of light. Any eavesdropping alien civilization will know all about our TV programs (probably a bad thing), will hear all our FM music (probably a good thing), and will know nothing of the politics of AM talk-show hosts like Rush Limbaugh (probably a safe thing).

Most plasmas are not friendly to organic matter. The person with the most hazardous job on the *Star Trek* television series is the one who must investigate the glowing blobs of plasma on the uncharted planets they visit. (My memory tells me that this person always wore a red shirt.) Every time this crew member meets a plasma blob, he gets vaporized. Born in the twenty-third century, these space-faring, star-trekking people would, you'd think, have long ago learned to treat plasma with respect (or not to wear red). We in the twenty-first century know enough to treat plasma with respect, and we haven't been anywhere.

In the center of our thermonuclear fusion reactors, where plasmas are monitored at a safe distance, we attempt to slam together hydrogen nuclei at high speeds and turn them into heavier helium nuclei. By doing so, we liberate energy that could supply society's need for electricity. Problem is, we haven't yet succeeded in getting more energy out than we put in. To achieve such high collision speeds, a blob of hydrogen atoms must be raised to tens of millions of degrees—at least as hot as the center of the Sun, where thermonuclear fusion is a routine thing. No hope for attached electrons here. At these temperatures they've all been stripped from their hydrogen atoms and roam free. How might you hold a glowing blob of hydrogen plasma at millions of degrees? In what container would you place it? Even microwave-safe Tupperware will not do.

What you need is a bottle that will not melt, vaporize, or decompose. To design it, we'd use the relationship between plasma and magnetic fields to our advantage, creating a container whose walls are intense magnetic fields that the plasma cannot cross. One of the pesky problems with the confinement of plasma is that if you squeeze it in one place, it tends to pop out someplace else. It's like trying to squeeze a balloon to make it smaller. The economic return from a successful fusion reactor will rest in part on the design of this magnetic "bottle" and on our understanding of how the plasma interacts with it.

You'd think those *Star Trek* people would have learned to treat plasma with respect.

Among the most exotic forms of matter ever concocted is the quark-gluon plasma, newly created by physicists at the Brookhaven National Laboratory, a particle-accelerator facility on New York's Long Island. Rather than being filled with atoms stripped of their electrons, a quark-gluon plasma comprises a mixture of some of the most basic constituents of matter: fractionally charged quarks along with the gluons that normally hold them together to form protons and neutrons. This unusual form of plasma greatly resembles the state of our trillion-degree cosmos a few microseconds after the big bang—about the time the observable universe was not much larger than our solar system. Indeed, in one form or another, every cubic inch of the universe was in a plasma state until a half-million years had elapsed.

A half-million years into its history, the universe had cooled down to a few thousand degrees. Before then, all light was getting scattered to and fro by the free electrons in the plasma—a phenomenon that greatly resembles what happens to light as it passes through frosted glass or through the Sun's interior. Light can travel through neither without scattering, and this renders both of them translucent instead of transparent. As the universe cooled to below a few thousand degrees, each electron in the cosmos combined with an atomic nucleus, creating complete atoms of hydrogen and helium and trace amounts of lithium.

As soon as every electron had found a home, the pervasive plasma state no longer existed. And that's the way it would stay for hundreds of millions of years, at least until quasars were born, with their central black holes that dine on swirling gases. Just before the gas falls in, it releases ionizing ultraviolet light that travels across the universe, kicking electrons back out of their atoms with abandon. Until the emergence of quasars, the universe enjoyed the only interval of time (before or since) when plasma was nowhere to be found. We call this era the dark ages and look upon it as a time when gravity was silently and invisibly assembling matter into the plasma balls that became the first generation of stars.

Neil de Grasse Tyson, an astrophysicist, is the Frederick P. Rose Director of New York City's Hayden Planetarium. He is (along with Steven Soter) coeditor of, as well as a contributor to, Cosmic Horizons: Astronomy at the Cutting Edge, *a collection of essays written by astrophysicists working on the frontiers of cosmological research.*

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By Sarah Blaffer Hrdy

Mothers and Others

FROM QUEEN BEES TO ELEPHANT MATRIARCHS, MANY ANIMAL MOTHERS ARE ASSISTED BY OTHERS IN REARING OFFSPRING. ANTHROPOLOGIST SARAH BLAFFER HRDY MAINTAINS THAT OUR HUMAN ANCESTORS, TOO, WERE "COOPERATIVE BREEDERS"—A MODE OF LIFE THAT ENABLED THEM TO THRIVE IN MANY NEW ENVIRONMENTS. TODAY, ARGUES HRDY, OUR CONTINUED ABILITY TO RAISE EMOTIONALLY HEALTHY CHILDREN MAY WELL DEPEND ON HOW WELL WE UNDERSTAND THE COOPERATIVE ASPECT OF OUR EVOLUTIONARY HERITAGE.

Her child on her back, a mother fishes with a basket in the Okavango River in Botswana.

Mother apes—chimpanzees, gorillas, orangutans, humans—dote on their babies. And why not? They give birth to an infant after a long gestation and, in most cases, suckle it for years. With humans, however, the job of providing for a juvenile goes on and on. Unlike all other ape babies, ours mature slowly and reach independence late. A mother in a foraging society may give birth every four years or so, and her first few children remain dependent long after each new baby arrives; among nomadic foragers, grown-ups may provide food to children for eighteen or more years. To come up with the 10–13 million calories that anthropologists such as Hillard Kaplan calculate are needed to rear a young human to independence, a mother needs help.

So how did our prehuman and early human ancestresses living in the Pleistocene Epoch (from 1.6 million until roughly 10,000 years ago) manage to get those calories? And under what conditions would natural selection allow a female ape to produce babies so large and slow to develop that they are beyond her means to rear on her own?

The old answer was that fathers helped out by hunting. And so they do. But hunting is a risky occupation, and fathers may die or defect or take up with other females. And when they do, what then? New evidence from surviving traditional cultures suggests that mothers in the Pleistocene may have had a significant degree of help—from men who thought they just might have been the

fathers, from grandmothers and great-aunts, from older children.

These helpers other than the mother, called allomothers by sociobiologists, do not just protect and provision youngsters. In groups such as the Efe and Aka Pygmies of central Africa, allomothers actually hold children and carry them about. In these tight-knit communities of communal foragers—within which men, women, and children still hunt with nets, much as humans are thought to have done tens of thousands of years ago—siblings, aunts, uncles, fathers, and grandmothers hold newborns on the first day of life. When University of New Mexico anthropologist Paula Ivey asked an Efe woman, "Who cares for babies?" the immediate answer was, "We all do!" By three weeks of age, the babies are in contact with allomothers 40 percent of the time. By eighteen weeks, infants actually spend more time with allomothers than with their gestational mothers. On average, Efe babies have fourteen different caretakers, most of whom are close kin. According to Washington State University anthropologist Barry Hewlett, Aka babies are within arm's reach of their fathers for more than half of every day.

Accustomed to celebrating the antiquity and naturalness of mother-centered models of child care, as well as the nuclear family in which the mother nurtures while the father provides, we Westerners tend to regard the practices of the Efe and the Aka as exotic. But to sociobiologists, whose stock in trade is comparisons across species, all this helping has a familiar ring. It's called cooperative breeding. During the past quarter century, as anthropologists and sociobiologists started to compare notes, one of the spectacular surprises has been how much allomaternal care goes on, not just within various human societies but among animals generally. Evidently, diverse organisms have converged on cooperative breeding for the best of evolutionary reasons.

A broad look at the most recent evidence has

Cooperative breeding allows many members of the dog family to rear large litters. Below: An arctic wolf and her puppies.

convinced me that cooperative breeding was the strategy that permitted our own ancestors to produce costly, slow-maturing infants at shorter intervals, to take advantage of new kinds of resources in habitats other than the mixed savanna-woodland of tropical Africa, and to spread more widely and swiftly than any primate had before. We already know that animal mothers who delegate some of the costs of infant care to others are thereby freed to produce more or larger young or to breed more frequently. Consider the case of silver-backed jackals. Patricia Moehlman, of the World Conservation Union, has shown that for every extra helper bringing back food, jackal parents rear one extra pup per litter. Cooperative breeding also helps various species expand into habitats in which they would normally not be able to rear any young at all. Florida scrub-jays, for example, breed in an exposed landscape where unrelenting predation from hawks and snakes usually precludes the fledging of young; survival in this habitat is possible only because older siblings help guard and feed the young. Such cooperative arrangements permit animals as different as naked mole rats (the social insects of the mammal world) and wolves to move into new habitats and sometimes to spread over vast areas.

WHEN ANIMAL MOTHERS DELEGATE SOME INFANT-CARE COSTS TO OTHERS, THEY CAN PRODUCE MORE OR LARGER YOUNG AND RAISE THEM IN LESS-THAN-IDEAL HABITATS.

What does it take to become a cooperative breeder? Obviously, this lifestyle is an option only for creatures capable of living in groups. It is facilitated when young but fully mature individuals (such as young Florida scrub-jays) do not or cannot immediately leave their natal group to breed on their own and instead remain among kin in their natal location. As with delayed maturation, delayed dispersal of young means that teenagers, "spinster" aunts, real and honorary uncles will be on hand to help their kin rear young. Flexibility is another criterion for cooperative breeders. Helpers must be ready to shift to breeding mode should the opportunity arise. In marmosets and tamarins—the little South American monkeys that are, besides us, the only full-fledged cooperative breeders among primates—a female has to be ready to be a helper this year and a mother the next. She may have one mate or several. In canids such as wolves or wild dogs, usually only the dominant, or alpha, male and female in a pack reproduce, but younger group members hunt with the mother and return to the den to regurgitate predigested meat into the mouths of her pups. In a fascinating instance of physiological flexibility, a subordinate female may actually undergo hormonal transformations similar to those of a real pregnancy: her belly swells, and she begins to manufacture milk and may help nurse the pups of the alpha pair. Vestiges of cooperative breeding crop up as well in domestic dogs, the distant descendants of wolves. After undergoing a pseudopregnancy, my neighbors' Jack Russell terrier chased away the family's cat and adopted and suckled her kittens. To suckle the young of another species is hardly what Darwinians call an adaptive trait (because it does not contribute to the surrogate's own survival). But in the environment in which the dog family evolved, a female's tendency to respond when infants signaled their need—combined with her capacity for pseudopregnancy—would have increased the survival chances for large litters born to the dominant female.

According to the late W. D. Hamilton, evolutionary logic predicts that an animal with poor prospects of reproducing on his or her own should be predisposed to assist kin with better prospects so that at least some of their shared genes will be perpetuated. Among wolves, for example, both male and female helpers in the pack are likely to be genetically related to the alpha litter and to have good reasons for not trying to reproduce on their own: in a number of cooperatively breeding species (wild dogs, wolves, hyenas, dingoes, dwarf mongooses, marmosets), the helpers do try, but the dominant female is likely to bite their babies to death. The threat of coercion makes postponing ovulation the better part of valor, the least-bad option for females who must wait to breed until their circumstances improve, either through the death of a higher-ranking female or by finding a mate with an unoccupied territory.

One primate strategy is to line up extra fathers. Among common marmosets and several species of tamarins, females mate with several males, all of which help rear her young. As primatologist Charles T. Snowdon points out, in three of the four genera of Callitrichidae (*Callithrix, Saguinus,* and

DAVID MACDONALD; OXFORD SCIENTIFIC FILMS

The meerkats of southwestern Africa's Kalahari Desert are cooperative breeders par excellence. Here, a subordinate "baby-sits" for another female's litter.

Leontopithecus), the more adult males the group has available to help, the more young survive. Among many of these species, females ovulate just after giving birth, perhaps encouraging males to stick around until after babies are born. (In cotton-top tamarins, males also undergo hormonal changes that prepare them to care for infants at the time of birth.) Among cooperative breeders of certain other species, such as wolves and jackals, pups born in the same litter can be sired by different fathers.

Human mothers, by contrast, don't ovulate again right after birth, nor do they produce offspring with more than one genetic father at a time. Ever inventive, though, humans solve the problem of enlisting help from several adult males by other means. In some cultures, mothers rely on a peculiar belief that anthropologists call partible paternity—the notion that a fetus is built up by contributions of semen from all the men with whom women have had sex in the ten months or so prior to giving birth. Among the Canela, a matrilineal tribe in Brazil studied for many years by William Crocker of the Smithsonian Institution, publicly sanctioned intercourse between women and men other than their husbands—sometimes many men—takes place during villagewide ceremonies. What might lead to marital disaster elsewhere works among the Canela because the men believe in partible paternity. Across a broad swath of South America—from Paraguay up into Brazil, westward to Peru, and northward to Venezuela—mothers rely on this convenient folk wisdom to line up multiple honorary fathers to help them provision both themselves and their children. Over hundreds of generations, this belief has helped children thrive in a part of the world where food sources are unpredictable and where husbands are as likely as not to return from the hunt empty-handed.

KONRAD WOTHE; MINDEN PICTURES

Two African elephant females tend a newborn calf. The larger social group facilitates the mother's task of rearing a single, large, slow-maturing offspring.

The Bari people of Venezuela are among those who believe in shared paternity, and according to anthropologist Stephen Beckerman, Bari children with more than one father do especially well. In Beckerman's study of 822 children, 80 percent of those who had both a "primary" father (the man married to their mother) and a "secondary" father survived to age fifteen, compared with 64 percent survival for those with a primary father alone. Not surprisingly, as soon as a Bari woman suspects she is pregnant, she accepts sexual advances from the more successful fishermen or hunters in her group. Belief that fatherhood can be shared draws more men into the web of possible paternity, which effectively translates into more food and more protection.

But for human mothers, extra mates aren't the only source of effective help. Older children, too, play a significant role in family survival. University of Nebraska anthropologists Patricia Draper and Raymond Hames have just shown that among !Kung hunters and gatherers living in the Kalahari Desert, there is a significant correlation between how many children a parent successfully raises and how many older siblings were on hand to help during that person's own childhood.

ONE PRIMATE STRATEGY IS TO LINE UP EXTRA "FATHERS." IN SOME SPECIES OF MARMOSETS, FEMALES MATE WITH SEVERAL MALES, ALL OF WHICH HELP HER RAISE HER YOUNG.

Older matrilineal kin may be the most valuable helpers of all. University of Utah anthropologists Kristen Hawkes and James O'Connell and their UCLA colleague Nicholas Blurton Jones, who have demonstrated the important food-gathering role of older women among Hazda hunter-gatherers in Tanzania, delight in explaining that since human life spans may extend for a few decades after menopause, older women become available to care for—and to provide vital food for—children born to younger kin. Hawkes, O'Connell, and Blurton Jones further believe that dating from the earliest days of *Homo erectus,* the survival of weaned children during food shortages may have depended on tubers dug up by older kin.

At various times in human history, people have also relied on a range of customs, as well as on coercion, to line up allomaternal assistance—for example, by using slaves or hiring poor women as wet nurses. But all the helpers in the world are of no use

if they're not motivated to protect, carry, or provision babies. For both humans and nonhumans, this motivation arises in three main ways: through the manipulation of information about kinship; through appealing signals coming from the babies themselves; and, at the heart of it all, from the endocrinological and neural processes that induce individuals to respond to infants' signals. Indeed, all primates and many other mammals eventually respond to infants in a nurturing way if exposed long enough to their signals. Trouble is, "long enough" can mean very different things in males and females, with their very different response thresholds.

For decades, animal behaviorists have been aware of the phenomenon known as priming. A mouse or rat encountering a strange pup is likely to respond by either ignoring the pup or eating it. But presented with pup after pup, rodents of either sex eventually become sensitized to the baby and start caring for it. Even a male may gather pups into a nest and lick or huddle over them. Although nurturing is not a routine part of a male's repertoire, when sufficiently primed he behaves as a mother would. Hormonal change is an obvious candidate for explaining this transformation. Consider the case of the cooperatively breeding Florida scrub-jays studied by Stephan Schoech, of the University of Memphis. Prolactin, a protein hormone that initiates the secretion of milk in female mammals, is also present in male mammals and in birds of both sexes. Schoech showed that levels of prolactin go up in a male and female jay as they build their nest and incubate eggs and that these levels reach a peak when they feed their young. Moreover, prolactin levels rise in the jays' nonbreeding helpers and are also at their highest when they assist in feeding nestlings.

As it happens, male, as well as immature and nonbreeding female, primates can respond to infants' signals, although quite different levels of exposure and stimulation are required to get them going. Twenty years ago, when elevated prolactin levels were first reported in common marmoset males (by Alan Dixson, for *Callithrix jacchus*), many scientists refused to believe it. Later, when the finding was confirmed, scientists assumed this effect would be found only in fathers. But based on work by Scott Nunes, Jeffrey Fite, Jeffrey French, Charles Snowdon, Lucille Roberts, and many others—work that deals with a variety of species of marmosets and tamarins—we now know that all sorts of hormonal changes are associated with increased nurturing in males. For example, in the tufted-eared marmosets studied by French and colleagues, testosterone levels in males went down as they engaged in caretaking after the birth of an infant.

CARLA Y. BOE

JOE MCDONALD; ANIMALS ANIMALS

Adult mammals are adapted to recognize and respond to infant signals, sometimes even across species. Left: A male pygmy marmoset with twin daughters. Below: A house cat nurses an orphaned eastern gray squirrel.

Testosterone levels tended to be lowest in those with the most paternal experience.

The biggest surprise, however, has been that something similar goes on in males of our own species. Anne Storey and colleagues in Canada have reported that prolactin levels in men who were living with pregnant women went up toward the end of the pregnancy. But the most significant finding was a 30 percent drop in testosterone in men right after the birth. (Some endocrinologically literate wags have proposed that this drop in testosterone levels is due to sleep deprivation, but this would probably not explain the parallel testosterone drop in marmoset males housed with parturient females.) Hormonal changes during pregnancy and lactation are, of course, indisputably more pronounced in mothers than in the men consorting with them, and no one is suggesting that male consorts are equivalent to mothers. But both sexes are surprisingly susceptible to infant signals—explaining why fathers, adoptive parents, wet

Yoruba girls in Benin: In many human societies, older siblings play a key role as mothers' helpers.

GENETIC RELATEDNESS ALONE IS A SURPRISINGLY UNRELIABLE PREDICTOR OF LOVE. WHAT MATTERS ARE CUES FROM INFANTS AND HOW WE PROCESS THESE CUES EMOTIONALLY.

VICTOR ENGLEBERT

nurses, and day-care workers can become deeply involved with the infants they care for.

Genetic relatedness alone, in fact, is a surprisingly unreliable predictor of love. What matters are cues from infants and how these cues are processed emotionally. The capacity for becoming emotionally hooked—or primed—also explains how a fully engaged father who is in frequent contact with his infant can become more committed to the infant's well-being than a detached mother will.

But we can't forget the real protagonist of this story: the baby. From birth, newborns are powerfully motivated to stay close, to root—even to creep—in quest of nipples, which they instinctively suck on. These are the first innate behaviors that any of us engage in. But maintaining contact is harder for little humans to do than it is for other primates. One problem is that human mothers are not very hairy, so a human mother not only has to position the baby on her breast but also has to keep him there. She must be motivated to pick up her baby even *before* her milk comes in, bringing with it a host of hormonal transformations.

Within minutes of birth, human babies can cry and vocalize just as other primates do, but human newborns can also read facial expressions and make a few of their own. Even with blurry vision, they engage in eye-to-eye contact with the people around them. Newborn babies, when alert, can see about eighteen inches away. When people put their faces within range, babies may reward this attention by looking back or even imitating facial expressions. Orang and chimp babies, too, are strongly attached to and interested in their mothers' faces. But unlike humans, other ape mothers and infants do not get absorbed in gazing deeply into each other's eyes.

To the extent that psychiatrists and pediatricians have thought about this difference between us and the other apes, they tend to attribute it to human mental agility and our ability to use language. Interactions between mother and baby, including vocal play and babbling, have been interpreted as protoconversations: revving up the baby to learn to talk. Yet even babies who lack face-to-face stimulation—babies born blind, say—learn to talk. Furthermore, humans are not the only primates to engage in the continuous rhythmic streams of vocalization known as babbling. Interestingly, marmoset and tamarin babies also babble. It may be that the infants of cooperative breeders are specially equipped to communicate with caretakers. This is

A !Kung-San mother with her children: Among traditional foragers, having extra helpers may be what enables human mothers to supply enough of the millions of calories required to bring each child from infancy to independence.

MELVIN KONNER: ANTHRO PHOTOS

Mother and child in a day care center: A major study showed no ill effects from day care if the care was of high quality and infants had a secure relationship with parents to begin with.

not to say that babbling is not an important part of learning to talk, only to question which came first—babbling so as to develop into a talker, or a predisposition to evolve into a talker because among cooperative breeders, babies that babble are better tended and more likely to survive.

If humans evolved as cooperative breeders, the degree of a human mother's commitment to her infant should be linked to how much social support she herself can expect. Mothers in cooperatively breeding primate species can afford to bear and rear such costly offspring as they do only if they have help on hand. Maternal abandonment and abuse are very rarely observed among primates in the wild. In fact, the only primate species in which mothers are anywhere near as likely to abandon infants at birth as mothers in our own species are the other cooperative breeders. A study of cotton-top tamarins at the New England Regional Primate Research Center showed a 12 percent chance of abandonment if mothers had older siblings on hand to help them rear twins, but a 57 percent chance when no help was available. Overburdened mothers abandoned infants within seventy-two hours of birth.

This new way of thinking about our species' history, with its implications for children, has made

me concerned about the future. So far, most Western researchers studying infant development have presumed that living in a nuclear family with a fixed division of labor (mom nurturing, dad providing) is the normal human adaptation. Most contemporary research on children's psychosocial development is derived from John Bowlby's theories of attachment and has focused on such variables as how available and responsive the mother is, whether the father is present or absent, and whether the child is in the mother's care or in day care. Sure enough, studies done with this model in mind always show that children with less responsive mothers are at greater risk.

It is the baby, first and foremost, who senses how available and how committed its mother is. But I know of no studies that take into account the possibility that humans evolved as cooperative breeders and that a mother's responsiveness also happens to be a good indicator of her social supports. In terms of developmental outcomes, the most relevant factor might not be how securely or insecurely attached to the mother the baby is—the variable that developmental psychologists are trained to measure—but rather how secure the baby is in relation to *all* the people caring for him or her. Measuring attachment this way might help explain why even children whose relations with their mother suggest they are at extreme risk manage to do fine because of the interventions of a committed father, an older sibling, or a there-when-you-need-her grandmother.

IN COOPERATIVE BREEDERS, THE DEGREE OF A MOTHER'S COMMITMENT TO HER INFANT SHOULD CORRELATE WITH HOW MUCH SOCIAL SUPPORT SHE HERSELF CAN EXPECT.

The most comprehensive study ever done on how nonmaternal care affects kids is compatible with both the hypothesis that humans evolved as cooperative breeders and the conventional hypothesis that human babies are adapted to be reared exclusively by mothers. Undertaken by the National Institute of Child Health and Human Development (NICHD) in 1991, the seven-year study included 1,364 children and their families (from diverse ethnic and economic backgrounds) and was conducted in ten different U.S. locations. This extraordinarily ambitious study was launched because statistics showed that 62 percent of U.S. mothers with children under age six were working outside the home and that the majority of them (willingly or unwillingly) were back at work within three to five months of giving birth. Because this was an entirely new social phenomenon, no one really knew what the NICHD's research would reveal.

SUSAN MEISELAS; MAGNUM PHOTOS, INC.

Because of our long life spans, we humans may be uniquely able to supplement the child-rearing efforts of younger kin.

The study's main finding was that both maternal and hired caretakers' sensitivity to infant needs was a better predictor of a child's subsequent development and behavior (such traits as social "compliance," respect for others, and self-control were measured) than was actual time spent apart from the mother. In other words, the critical variable was not the continuous presence of the mother herself but rather how secure infants felt when cared for by someone else. People who had been convinced that babies need full-time care from mothers to develop normally were stunned by these results, while advocates of day care felt vindicated. But do these and other, similar findings mean that day care is not something we need to worry about anymore?

Not at all. We should keep worrying. The NICHD study showed only that day care was better than mother care if the mother was neglectful or abusive. But excluding such worst-case scenarios, the study showed no detectable ill effects from day care *only* when infants had a secure relationship with parents to begin with (which I take to mean that babies felt wanted) and *only* when the day care was of high quality. And in this study's context, "high quality" meant that the facility had a high ratio of caretakers to babies, that it had the same caretakers all the time, and that the caretakers were sensitive to infants' needs—in other words, that the day care staff acted like committed kin.

Bluntly put, this kind of day care is almost impossible to find. Where it exists at all, it's expensive. Waiting lists are long, even for cheap or inadequate care. The average rate of staff turnover in

day care centers is 30 percent per year, primarily because these workers are paid barely the minimum wage (usually less, in fact, than parking-lot attendants). Furthermore, day care tends to be age-graded, so even at centers where staff members stay put, kids move annually to new teachers. This kind of day care is unlikely to foster trusting relationships.

CHIEN-CHI CHANG; MAGNUM PHOTOS, INC.

Children at a garment-industry day care center in New York City: For a developing child, the most practical way to behave might vary drastically, depending upon the commitment and sensitivity of its earliest caretakers.

What conclusion can we draw from all this? Instead of arguing over "mother care" versus "other care," we need to make day care better. And this is where I think today's evolution-minded researchers have something to say. Impressed by just how variable child-rearing conditions can be in human societies, several anthropologists and psychologists (including Michael Lamb, Patricia Draper, Henry Harpending, and James Chisholm) have suggested that babies are up to more than just maintaining the relationship with their mothers. These researchers propose that babies actually monitor mothers to gain information about the world they have been born into. Babies ask, in effect, Is this world filled with people who are going to provide for me and help me survive? Can I count on them to care about me? If the answer to those questions is yes, they begin to sense that developing a conscience and a capacity for compassion would be a great idea. If the answer is no, they may then be asking, Can I not afford to count on others? Would I be better off just grabbing what I need, however I can? In this case, empathy, or thinking about others' needs, would be more of a hindrance than a help.

DANNY LYON; MAGNUM PHOTOS, INC.

For a developing baby and child, the most practical way to behave might vary drastically, depending on whether the mother has kin who help, whether the father is around, whether foster parents are well-meaning or exploitative. These factors, however unconsciously perceived by the child, affect important developmental decisions. Being extremely self-centered or selfish, being oblivious to others or lacking in conscience—traits that psychologists and child-development theorists may view as pathological—are probably quite adaptive traits for an individual who is short on support from other group members.

If I am right that humans evolved as cooperative breeders, Pleistocene babies whose mothers lacked social support and were less than fully committed to infant care would have been unlikely to survive. But once people started to settle down—10,000 or 20,000 or perhaps 30,000 years ago—the picture changed. Ironically, survival chances for neglected children increased. As people lingered longer in one place, eliminated predators, built walled houses, stored food—not to mention inventing things such as rubber nipples and pasteurized milk—infant survival became decoupled from continuous contact with a caregiver.

Since the end of the Pleistocene, whether in preindustrial or industrialized environments, some children have been surviving levels of social neglect that previously would have meant certain death. Some children get very little attention,

A boy and his younger sister

IN EFFECT, BABIES ASK: IS THIS WORLD FILLED WITH PEOPLE WHO ARE GOING TO PROVIDE FOR ME AND HELP ME SURVIVE? CAN I COUNT ON THEM TO CARE ABOUT ME?

even in the most benign of contemporary homes. In the industrialized world, children routinely survive caretaking practices that an Efe or a !Kung mother would find appallingly negligent. In traditional societies, no decent mother leaves her baby alone at any time, and traditional mothers are shocked to learn that Western mothers leave infants unattended in a crib all night.

Without passing judgment, one may point out that only in the recent history of humankind could infants deprived of supportive human contact survive to reproduce themselves. Certainly there are a lot of humanitarian reasons to worry about this sit-

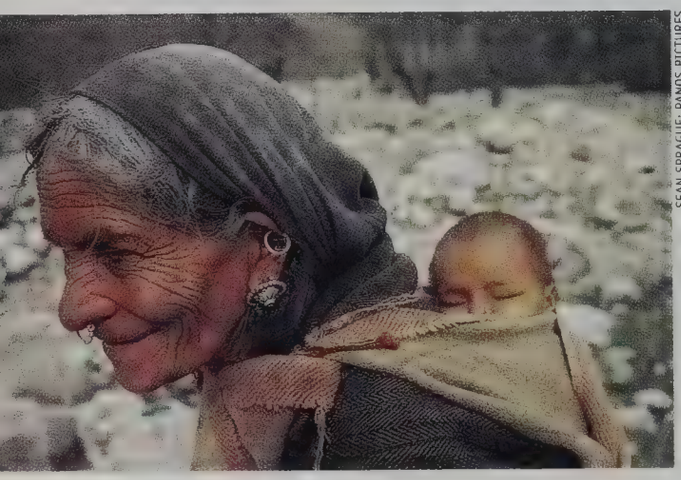
uation: one wants each baby, each child, to be lovingly cared for. From my evolutionary perspective, though, even more is at stake.

Even if we manage to survive what most people are worrying about—global warming, emergent diseases, rogue viruses, meteorites crashing into earth—will we still be human thousands of years down the line? By that I mean human in the way we currently define ourselves. The reason our species has managed to survive and proliferate to the extent that 6 billion people currently occupy the planet has to do with how readily we can learn to cooperate when we want to. And our capacity for empathy is one of the things that made us good at doing that.

At a rudimentary level, of course, all sorts of creatures are good at reading intentions and movements and anticipating what other animals are going to do. Predators from gopher snakes to lions have to be able to anticipate where their quarry will dart. Chimps and gorillas can figure out what another individual is likely to know or not know. But compared with that of humans, this capacity to entertain the psychological perspective of other individuals is crude.

Below: Woman and grandchild in Himachal Pradesh, India. Opposite: Pregnant mother with child, United States.

The capacity for empathy is uniquely well developed in our species, so much so that many people (including me) believe that along with language and symbolic thought, it is what makes us human. We are capable of compassion, of understanding other people's "fears and motives, their longings and griefs and vanities," as novelist Edmund White puts it. We spend time and energy worrying about people we have never even met, about babies left in dumpsters, about the existence of more than 12 million AIDS orphans in Africa.



SEAN SPRAGUE; PANOS PICTURES

Psychologists know that there is a heritable component to emotional capacity and that this affects the development of compassion among individuals. By fourteen months of age, identical twins (who share all genes) are more alike in how they react to an experimenter who pretends to painfully pinch her finger on a clipboard than are fraternal twins (who share only half their genes). But empathy also has a learned component, which has more to do with analytical skills. During the first years of life, within the context of early relationships with mothers and other committed caretakers, each individual learns to look at the world from someone else's perspective.

And this is why I get so worried. Just because humans have evolved to be smart enough to chronicle our species' histories, to speculate about its origins, and to figure out that we have about 30,000 genes in our genome is no reason to assume that evolution has come to a standstill. As gene frequencies change, natural selection acts on the outcome, the expression of those genes. No one doubts, for instance, that fish benefit from being able to see. Yet species reared in total darkness—as are the small, cave-dwelling characin of Mexico—fail to develop their visual capacity. Through evolutionary time, traits that are unexpressed are eventually lost. If populations of these fish are isolated in caves long enough, youngsters descended from those original populations will no longer be able to develop eyesight at all, even if reared in sunlight.

DURING EARLY CHILDHOOD, THROUGH RELATIONSHIPS WITH MOTHERS AND OTHER CARETAKERS, INDIVIDUALS LEARN TO LOOK AT THE WORLD FROM SOMEONE ELSE'S PERSPECTIVE.

If human compassion develops only under particular rearing conditions, and if an increasing proportion of the species survives to breeding age without developing compassion, it won't make any difference how useful this trait was among our ancestors. It will become like sight in cave-dwelling fish.

No doubt our descendants thousands of years from now (should our species survive) will still be bipedal, symbol-generating apes. Most likely they will be adept at using sophisticated technologies. But will they still be human in the way we, shaped by a long heritage of cooperative breeding, currently define ourselves? □

This article was adapted from "Cooperation, Empathy, and the Needs of Human Infants," a Tanner Lecture delivered at the University of Utah. It is used with the permission of the Tanner Lectures on Human Values, a Corporation, University of Utah, Salt Lake City.

New Zealand Sweet Stakes

Sugar was a shared resource in a forest community until a greedy newcomer moved in.

By Laura Sessions

Biologist E. O. Wilson has called invertebrates "little things that run the world," because of their numbers, variety, and influence on larger organisms and even entire ecosystems. New Zealand is home to "little things" that, while each only a few millimeters long, have benignly modified about 250 million acres of the country's beech forests. Known as sooty beech scale insects, these agents turn the resources of the beech trees into a substance crucial to their own survival and to that of other forest dwellers, from fungi to birds. The association of the insects and the trees is an ancient one, and the expansive food web in which they are actors was, until recently, intact.

Sooty beech scale insects (*Ultracoelostoma assimile* and *U. brittini*) are sap suckers, or homopterans, that grow in the furrowed bark of four species of southern beech trees *(Nothofagus)* in New Zealand. During its complex life cycle, the beech scale insect goes through several developmental stages called instars. The females pass through four stages, the males five. Second- and third-instar females insert their long mouthparts into the cells of a beech's phloem—the tissues that carry nutrients through the tree—and suck up sugars. After satisfying their appetites, they excrete the excess sap and wastes through a waxy anal tube. A sweet liquid, called honeydew, accumulates one drop at a time at the tip of this tube, which looks like a thin white thread.

Homopterans are common and widespread. Most of the world's 33,000 species produce honeydew, but few can match the beech scale's enormous and constant output of the substance. In the Northern Hemisphere, honeydew producers such as aphids are active only seasonally, but beech scale insects draw off and convert energy from beech trees year-round, and they do so copiously during the austral summer. From January to April, the tree trunks in a southern beech forest often shimmer with a thick coat of honeydew, and the droplets' heady, sweet smell fills the air.

A tiny sap-sucking invertebrate, the sooty beech scale insect (in early developmental stage, right) has a big impact on millions of acres of New Zealand's beech trees, opposite.

In some forests, ten and a half square feet of tree

GRANT STIRLING; HEDGEHOG HOUSE, NEW ZEALAND

Right: A drop of honeydew—a sugary liquid excreted through a threadlike tube by a scale insect—is poised to fall. Drops are avidly eaten by forest dwellers such as the introduced honeybee, above, and the kaka, a native parrot, opposite page.

trunk (think of the top of an average card table) may support as many as 2,000 scale insects. More than 40 percent of the food the trees have produced through photosynthesis may be lost to sooty beech scale insects. These beeches do not appear to be harmed, although for most plants, losses of much less than 40 percent of their energy reserves would be insupportable. Currently, scientists can only guess how the trees are able to withstand such a drain, but various theories are being explored. Possibly only the more vigorous and faster-growing beech trees are tapped by beech scale insects. Fallen drops may recycle sugars to the soil and thence to trees, or the insects may promote extra photosynthesis in host trees.

Researchers have a better understanding of honeydew's huge importance to other organisms that live in southern beech forests. Because these forests are less diverse than many other forest types and because few of the resident plants provide fleshy fruits or abundant nectar, many native birds, lizards, insects, and other invertebrates rely on honeydew for a high-energy food, sipping drops directly from the threadlike tubes. (The beech scale itself benefits from honeydew feeders; removal of the sticky honeydew stimulates the flow of sap through the insect's digestive system, preventing "constipation.")

In the Northern Hemisphere, more than 250 invertebrate species—ants in particular—have been recorded feeding on honeydew. In European forests, for example, ants consume about two-thirds of the honeydew produced by aphids and other sap-sucking insects. New Zealand has only a few native ant species; here it is birds, rather than invertebrates, that avidly feed on the honeydew. While some New Zealand caterpillars and beetles do rely on honeydew for food, invertebrates more often benefit indirectly from a fungus that grows on the sticky drops. The fungus provides invertebrates with food and with lodging in its spongy interior and fissured sur-

Often solitary during the day as they forage for insect larvae, kaka tend to gather at dusk at honeydew-rich sites, and the forest then rings with squawks and whistles as they socialize.

face. Aptly named the sooty mold fungus, this organism coats any surface where honeydew lands after falling from the insects' anal tubes—tree trunks, roots, shrubs, saplings, and even the forest floor. It may cover beech trees so thoroughly that their pale gray bark turns as black as charcoal, with new honeydew drops shining on top.

RAY GOLDING; HEDGEHOG HOUSE, NEW ZEALAND

Caterpillars, beetle larvae, and other invertebrates find a home in sooty mold and become a source of protein for foraging birds, but the honeydew provides the birds with essential energy. Bellbirds and tuis—forest birds in the nectar-feeding family called honeyeaters—have brushlike tongues that enable them to lap up honeydew drops easily. They hop up the beech trunks, licking as they go and occasionally pausing to clean the sticky sugars from their feathers. Most frequently they feed on the branches in the canopy, possibly because more honeydew is found in the higher limbs of the tree than near ground level. Honeyeaters spend more time in forests with honeydew than in forests without it. The birds will flock to beech forests during the winter, when fruit and nectar are scarce; tuis may spend more than 80 percent of their feeding time harvesting honeydew when it is plentiful. Without the scale insect and its sugary excretions, these birds would be much less common in beech forests, to the detriment of some resident plants. Honeyeaters are the primary pollinators for native mistletoes and certain other nectar-producing plants. If these birds decline, the plants will no longer be able to produce new seeds. (See "A Floral Twist of Fate," September 2000.)

Also reliant on honeydew are the threatened New Zealand parrots known as kaka. These large forest birds nest in holes in old trees and spend about a third of their feeding time collecting honeydew when it is abundant. Kaka can obtain enough energy for a whole day in just three hours of honeydew foraging. This fuel then allows the birds to exert themselves digging out beetle larvae, a vital source of protein, from under beech tree bark. Larvae of kanuka longhorn beetles are harvested only by the males, while females collect other kinds, usually from rotting trees. Often solitary during the day, kaka can become quite social when they forage on honeydew. They often gather at dusk at honeydew-rich sites, and the forest then rings with squawks and whistles as they interact. Now surviving only in remnant populations, kaka also congregate at the beginning of the breeding season, but today these gatherings may be only a weak reflection of their sociability a century ago, when flocks of more than a hundred could be seen.

In the late 1970s a new "little thing" entered the southern beech forest—an interloper that threatens to ruin the intricate honeydew food web. Accidentally introduced into New Zealand, common wasps *(Vespula vulgaris)* found the conditions perfect. With

ROSS ARMSTRONG; HEDGEHOG HOUSE, NEW ZEALAND

the warm climate, abundant honeydew, and lack of natural enemies, the wasps flourished and their numbers exploded. Before their arrival, other exotic social insects, such as honeybees, bumblebees, and German wasps (*Vespula germanica,* which entered via aircraft parts at the end of World War II), had diminished honeydew supplies to a degree, but common wasps have proved to be ruthlessly efficient. On average, thirty of their hives, most on the ground, can be found per acre. And whereas insects such as feral honeybees reach densities of 22 insects per ten and a half square feet of tree trunk (bear in mind the card table with 2,000 honeydew insects), more than 300 common wasps can occupy the same space. The yellow-and-black, bee-sized common wasps are also found in other types of forests but are most concentrated in honeydew beech forest, where, thanks to their voracity, they have largely displaced German wasps. In these forests, the biomass of common wasps exceeds that of many other creatures added together; if one were to collect all the common wasps and put them on a scale, they would outweigh all the resident birds, rodents, and stoats combined.

Experiments using devices that prevented wasps from landing on beech trees have shown that the large numbers of common wasps in beech forests are responsible for a reduction of up to 70 percent of annual, and fully 99 percent of austral summer, honeydew production. By removing such vast quantities of honeydew, wasps may alter nutrient cycles and perhaps decrease the soil quality for beech trees. Furthermore, because common wasps constantly revisit

Stoats are among the rogues' gallery of introduced creatures wreaking havoc on native wildlife. The juveniles below are in a clump of speargrass on the South Island.

the same areas of beech trunk, they do not allow the honeydew drops time to fully re-form and thus reduce the drops' size and sugar content. To fulfill their energy requirements, birds must eat many more of these smaller, less sweet drops and spend more time in search of them. If the drops become too small and scarce, birds may abandon honeydew altogether and try to search out whatever fruit, nectar, and other sugar sources may be available.

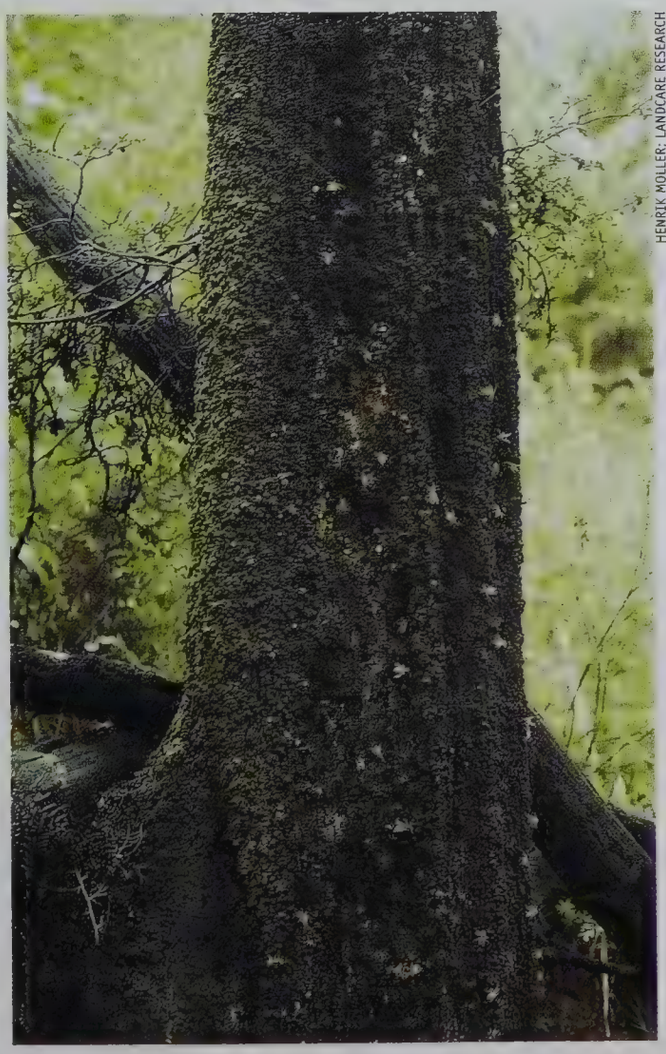
A scientist at Landcare Research in Nelson, New Zealand, Jacqueline Beggs has spent the past decade studying the effects of wasps in honeydew forests. She believes that the wasp-induced shortage of honeydew could contribute to a decline of native birds over the long term. Beggs has shown that when wasps reduce the number and size of drops below a certain level—a threshold reached when the insects revisit drops every six and a half hours—kaka give up even trying to feed on honeydew. Similarly, Henrik Moller, now at the University of Otago in Dunedin, New Zealand, and other colleagues at Landcare Research have shown that honeyeaters are even more sensitive. If wasps visit drops

If one were to collect all the introduced common wasps and put them on a scale, they would outweigh all of a honeydew beech forest's resident birds, rodents, and stoats combined.

at a rate of once every three hours, honeydew will be depleted to the point that bellbirds and tuis will switch to other food sources or be forced to conserve energy by spending less time on vital activities such as mating and nesting. Furthermore, when the bellbirds, tuis, kaka, and native insectivorous birds attempt to feed on native invertebrates, they again face competition from wasps, which devour spiders, caterpillars, ants, bees, and flies. Populations of these invertebrates have been decimated or even eradicated in areas where wasps are common.

Unfortunately, scientists do not know precisely how wasps may affect native species in the long run, partly because no one fully understands the organisms involved, especially the invertebrates, and partly because their interactions are so varied and complex. Land mammals are also a major problem. New Zealand has no native terrestrial mammals, but a raft of mammals has been introduced in the

KIM TAYLOR; BRUCE COLEMAN, INC.



HENRIK MOLLER; LANDCARE RESEARCH

The common wasp, above, first appeared in New Zealand in the late 1970s. Its numbers have since exploded. Left: A beech tree infested with honeydew-hungry wasps.

DON HADDEN; HEDGEHOG HOUSE, NEW ZEALAND

With nectar in short supply in the southern beech forest, two native species of honeyeaters (the bellbird, right, and tui, below) get their energy from honeydew.

MARK A. CHAPPELL; ANIMALS ANIMALS

last 100 to 150 years. Cats, rats, stoats, possums, and ferrets have had drastic effects on native plants and bird species, many of which are flightless and have few defenses against the invaders. It is therefore difficult to separate the "bottom-up" effects of little things like beech scale insects and wasps from the "top-down" effects of larger predators.

Wasps and mammals may interact to cause more serious harm than either group would alone. Possums, for example, eat many of the same things (such as mistletoe) that honeyeaters do, so the birds often cannot switch to other food types when wasps deplete the honeydew stores. Other effects of immigrant species have proved difficult to tease apart. During a long-term research project on the South Island of New Zealand, Beggs and Peter Wilson

Scientists estimate that if wasps visit honeydew drops at a rate of once every three hours, the honeydew will be so depleted that bellbirds and tuis will have to switch to other sources of energy.

also of Landcare Research, noted that kaka changed how they foraged and fed in response to competition with wasps for honeydew. However, the scientists could not test the overall effect of food shortage on the kaka's ability to raise young, because stoats had raided most of the nests, killing more than 70 percent of the kaka chicks and, even more dire, four of the seven nesting females. Female kaka incubate their clutches of one to five eggs for about twenty-four days; fledging takes a further seventy days. During these three months, both mother and chicks are at high risk of a stoat attack. Moreover, the death of females on their nests leads to a serious imbalance in the population; many breeding-aged males are unable to find a mate. Beggs and Wilson estimated that the kaka population they studied for ten years suffered 7 percent mortality, a rate that could cause this South Island population to become extinct in less than thirty years.

For native residents of southern beech forests to recover, New Zealanders have to play an active role. No pest-control measures currently available can turn the situation around, but various tools are being developed, such as the poisoning of wasp nests and the use of biological controls. This year one operation succeeded in eradicating 90 percent of the wasp nests within a 740-acre area, enough to restore the honeydew to natural levels and to protect other invertebrates from wasp predation. If, at last, this little invader and its mammalian counterparts are restrained, the reward will be southern beech forests once again alive with the songs of honeydew-collecting birds rather than the drone of invading wasps. □

The Rewards of Chance

By Mark Denny

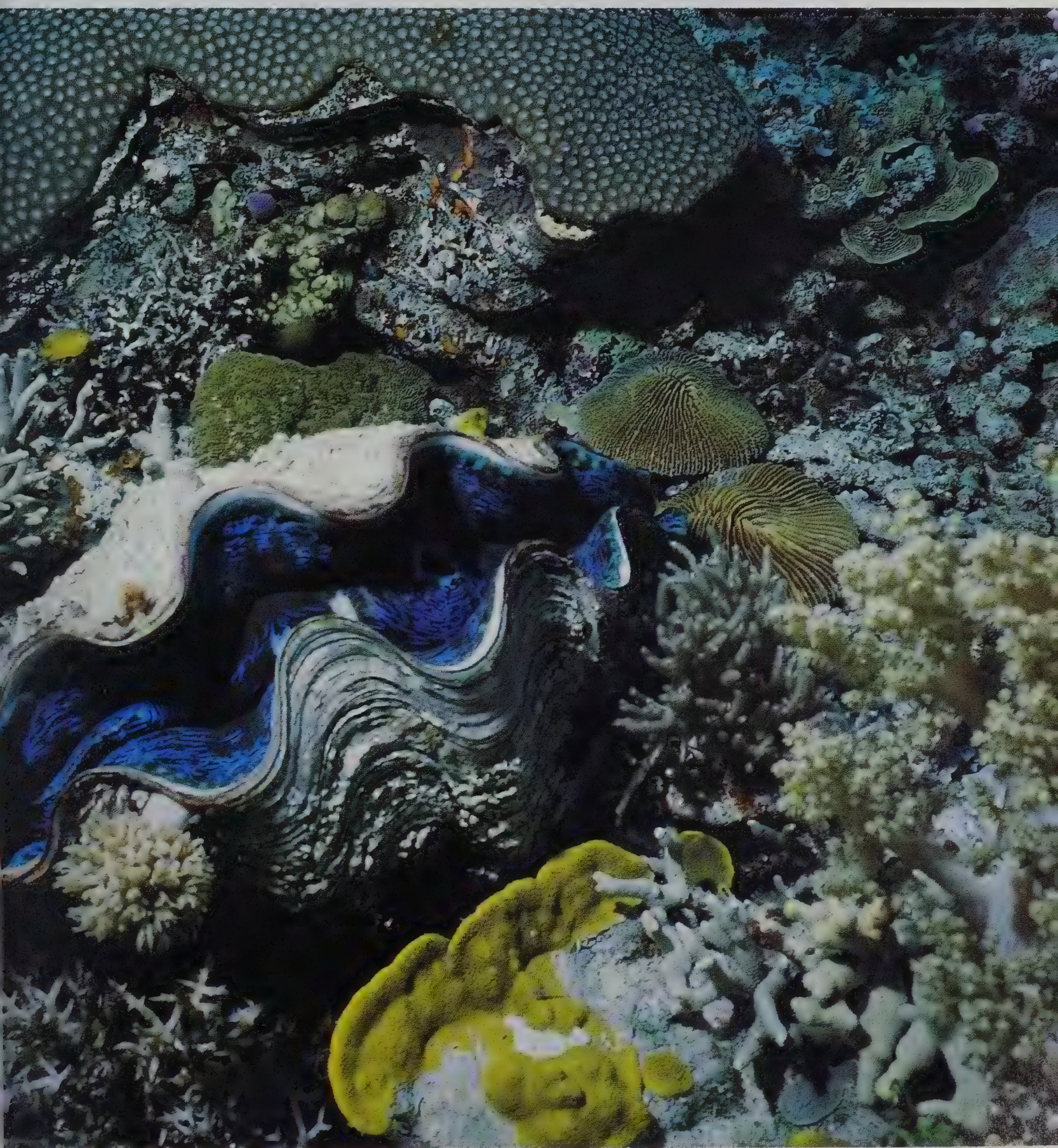
Sometimes the most profound messages in biology reside in the most pedestrian creatures. Consider the lowly clam. Slow afoot and very tasty, clams are attractive to a wide variety of predators. When threatened, a clam uses its strong adductor muscles to clamp its armorlike shells together, leaving no living material exposed and presenting a daunting task for any predator trying to gain entry. A serious difficulty arises, however, when the animal needs to open its shell again to breathe or feed. The muscles that caused the shell to "clam up" can't help, since they're effective at pulling but useless when it comes to pushing the shell open. To open up, the clam instead employs a peculiar material incorporated into the shell's hinge. As the shell closes, this material (a protein rubber called abductin) deforms—either stretching or compressing, depending on the species of clam. In the process, it stores mechanical energy, much as a garage-door spring stores energy. Later, when this energy is released, it provides the force needed to reopen the shell.

Rubbery materials are found in many animals besides clams. The wing supports of beetles, the neck ligaments of buffaloes, and the knees of fleas all contain structural elements made from materials akin to the man-made rubber in automobile tires and rubber bands. The walls of mammalian arteries provide a pertinent example. A mammalian heart is a pulsatile pump: during contractions, it squirts blood into the arteries, but it must then wait to refill before delivering the next pulse of fluid. Pumping in this intermittent fashion requires much more power than would be needed to move the same amount of blood in a steady stream. Fortunately, as the heart contracts, some of its power is used to stretch a protein rubber called elastin, found in the walls of the large arteries, thereby storing mechanical energy. As the heart refills, these arteries relax, releasing the energy. In essence, the arteries act as a

J. W. MOWBRAY; PHOTO RESEARCHERS, INC.

GIANT CLAM
A rubber protein in the hinges of its shell enables a clam to open up; muscles help it shut tight again.

Thanks to the random movements of agitated molecules, biological rubber allows clams to open wide and insects to fly efficiently.



secondary pump, smoothing out the uneven flow of blood and allowing our hearts to beat more efficiently. The circulatory systems of other vertebrates, as well as those of squids and octopuses, employ similar rubbery materials.

What gives rubbers this special ability to store mechanical energy? Surprisingly, perhaps, the answer is randomness. Biologists often bemoan chance events in nature, lamenting that if the world were just a bit more orderly, they would have an easier time understanding how life works. In fact, however, randomness can tell us a great deal about how plants and animals function.

Physicists long ago recognized the value of randomness. At room temperature, molecules of gas move at high speeds (a thousand feet or so per second), changing the direction of their flight frequently and at random as they bounce off one another. The random motion of gas molecules (the vigor of this motion being, as physicists would tell us, proportional to the temperature of the gas) is known as thermal agitation. This wild game of molecular billiards makes it impossible to predict exactly where any individual molecule will be at a given time or exactly what speed it will have, but physicists can use thermal agitation to make precise predictions about the behavior of the gas as a whole.

The stiffness and extensibility of rubber tissue in animals comes from random movements of proteins.

STEPHEN DALTON; NHPA

HARLEQUIN BEETLE
In many flying insects, rubbery materials provide the elasticity that helps the wing flap and fold.

For example, we speak of a gas in a container a being under pressure. The pressure comes from th impact of individual gas molecules on the con tainer's walls. Because the motion of molecules randomized by collisions, we can predict that th pressure is the same in all directions. Similar consid erations allow us to predict how gases diffuse. Again it is impossible to know exactly where any individ ual gas molecule will roam, but as long as all motio is random, we can accurately predict how the aver age location of molecules shifts through time.

By the same token, the random behavior o rubbery proteins allows us to predict how muc mechanical energy they can store. In mathematica terms, the amount of energy that a bit of materia can store is proportional to the material's stiffnes multiplied by its extensibility. Bone, for example, i very stiff (a lot of force is required to deform it) bu not very extensible (it can deform only 2 to 3 per cent before breaking). As a result, bone is relativel poor at storing energy. At the other end of th spectrum, mucus (such as that underlying the foo of a snail) is very extensible (it can easily stretch b 500 percent) but not at all stiff. So it, too, is poor a storing energy. The biological rubbers in animals however, epitomize the happy medium. They ar both reasonably stiff and highly extensible and weight for weight, can store nearly a hundred time as much energy as high-tensile-strength steel.

Their secret? A complex, three-dimensiona network of protein chains. In many respects, a pro tein chain (and what works for one chain holds fo the material as a whole) is analogous to the kind o bead-link chain that one finds attached to old fashioned bathtub stoppers. The overall length o such a chain is set by the number of beads, and al though the beads cannot be stretched apart, the can rotate relative to their neighbors. As a result, th chain is flexible. Similarly, each amino acid in a pro tein chain is a "bead" that can rotate around th peptide bonds that link the amino acids into th chain. Like the bead-link chain, the protein chai combines flexibility and a fixed length (in this case a fixed number of amino acids).

Imagine holding the ends of a bead-link chain one in each hand, and pulling the chain taut. Wit the chain fully extended, each link is in line with it neighbors, and the chain as a whole has a very or derly arrangement. There is, in fact, one and onl one arrangement of links that allows the chain to b stretched to its full length. Now, allow your hand

to move together a bit. With its ends closer together, the chain is free to take on new configurations, and if you shake it at random, it will rattle around among these configurations. The closer together your hands are, the more arrangements the chain can adopt and the more freedom it has to rattle around. The concept works the other way as well: if we somehow knew how many arrangements the chain could take, we could infer how close together its ends must be.

If you were to extend a protein chain to its full length, all the amino acid "beads" would be in a straight line, and the chain would be entirely ordered. In reality, however, this kind of order is unlikely. At the temperatures at which life occurs on earth, thermal agitation, including the agitation of amino-acid molecules, is constantly occurring. Consequently, as individual amino acids in a protein chain move about randomly, the chain becomes disordered. And just as with the bead-link chain, the more disordered the molecular chain becomes, the closer together (on average) its ends are.

Put another way, a rubbery protein chain tends to assume a disordered shape. Because the motion of the chain is random, we can never say for sure what this shape will be at any moment. But precisely because the motion is random, we can use statistics to describe the probability that the chain is in a particular configuration. Knowing these probabilities, we can then calculate the average shape of the molecule. In mathematical terms, that is because the average end-to-end distance of a fully disordered chain turns out to be proportional to the square root of the number of its links. For example, if a hypothetical rubber has 100 amino-acid links, then in its natural, disordered state the ends of the chain will be only about 10 amino-acid lengths apart.

What does all this have to do with the ability of clams to open wide, beetles to fly, and fleas to jump? Everything, as it turns out. In the hypothetical example cited above, a 100-link amino-acid chain can be extended tenfold before it is pulled taut. For similar reasons, most actual rubbers have no trouble extending three to four times their resting length. The stiffness of biological rubbers comes from the natural tendency of rubber protein chains to coil, requiring force to extend them. This stiffness, coupled with the chains' great extensibil-

AMERICAN BISON
Made in part of rubber protein, a huge ligament in the neck of a bison (or a cow, horse, or wildebeest) provides most of the force necessary to hold up the animal's massive head.

ity, accounts for the special ability of rubbery proteins to store mechanical energy.

Demonstrating that random molecular motion plays a necessary role in the mechanical properties of rubbers is easy. If a bit of rubber is cooled, the motion of its molecules is reduced and the material begins to lose its elasticity. For example, a rubber band that is resilient at room temperature becomes leathery and relatively inextensible when cooled in a kitchen freezer. This effect is, in large part, what doomed the space shuttle *Challenger*. *Challenger* was launched on an unusually cold day, and one of the rubber seals in its solid-fuel boosters was too stiff to function properly. Taken to an extreme, rubber cooled by liquid nitrogen behaves very much like glass: it is brittle and has very little capacity to store energy. Without random motion—that is, in the absence of heat—rubber is simply not rubbery. And without rubbery materials, neither clams nor human beings would operate as effectively as they do.

Only a few proteins are rubbery, however. In most of them, at least some of the amino acids are held rigidly together—by bonds between sulfur atoms in cystine molecules and by the hydrogen bonds and hydrophobic interactions among the so-called side chains of other amino acids. In addition, these side chains are often too bulky to permit them to move relative to their neighbors. Only when a protein is constructed from the right amino acids connected in the right order does the resulting chain have the flexibility necessary for rubbery behavior.

Paradoxically, randomness enables scientists to predict much about how nature works.

As important as rubbers are for animals, they are only one example of the utility of random behavior in nature. The same type of statistics that allows us to determine the average shape of protein chains can be used to predict a wide range of phenomena—from the force of waves breaking on a beach to the reason people are not deafened by the noise at a cocktail party. In these cases, the amplitude of ocean and sound waves, rather than the flexibility of protein chains, is involved, but the principle is the same. The message of the gaping clam is clear: far from being a frustrating obstacle, chance in nature is cause for celebration. □

TONY BRAIN/SPL: PHOTO RESEARCHERS, INC.

FLEA
Fleas are great jumpers, some leaping 200 times the length of their own bodies. This impressive ability is due to rubbery material that is compressed when the insect cocks its "knees" (the joints between its hind legs and its body).

RON DAHLQUIST

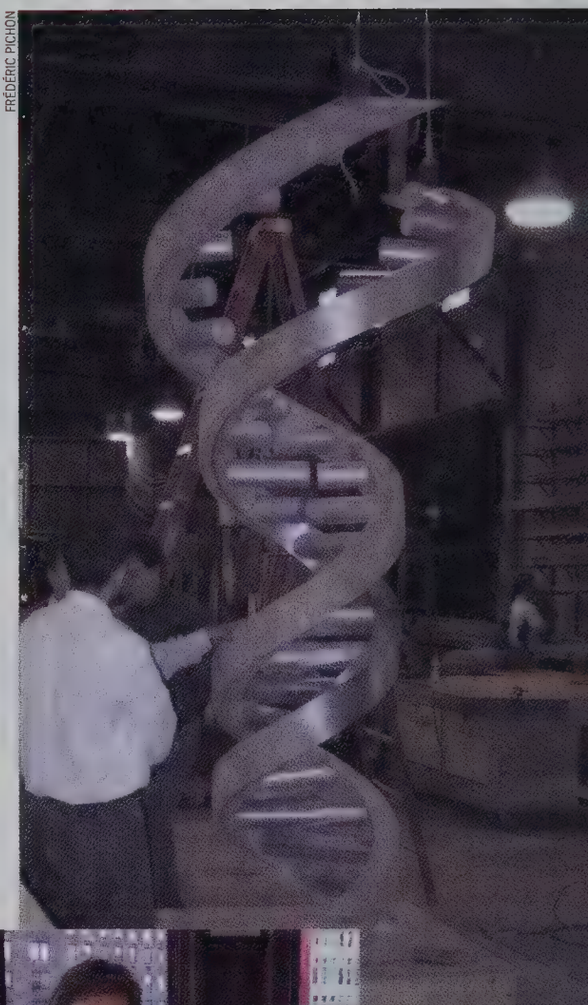
BREAKING WAVE
Chance is a powerful force in the physical, as well as the biological, world. As waves converge at sea, their crests and troughs combine randomly, determining the height and force of the waves that reach the shore.

AT THE MUSEUM

The Genome Writ Large

A new exhibition unravels the wonder, the promise, and the potential dangers of human DNA research.

By Henry S. F. Cooper Jr.



FRÉDÉRIC PICHON

DNA model under construction

DENIS FINNIN; AMNH

Michael J. Novacek

DENIS FINNIN; AMNH

Rob DeSalle

This past February 12, Charles Darwin's birthday, two versions of the human genome were announced—one produced by a public organization, the International Human Genome Sequencing Consortium, based in Cambridge, England, and the other by a private company, Celera Genomics in Rockville, Maryland. Now, on May 26, the Museum opens the exhibition "The Genomic Revolution." Dealing largely with invisible matter, the exhibition relies on models that gleam like jewels under spotlights and on glowing images projected across computer monitors and high-definition plasma screens, while LED displays spell out news of the genome direct from the laboratory in bright, ever-flowing letters.

Just past the entrance is a small installation devoted to James D. Watson and Francis H. C. Crick's revolutionary 1953 double-helix model of the structure of the DNA molecule. And straight ahead is a brand-new, floor-to-ceiling rendering of the double helix as an organic, undulating, slightly metallic serpent of the night. It's a long way from Watson and Crick's mechanical, tinker-toy affair.

Also near the entrance, in an encased glass vial, is a sample of the real thing: a single strand of DNA replicated thousands of times and forming a white mush. A parabolic mirror inside the case makes the DNA material appear to float overhead like a hologram. Three and a quarter billion nucleotides—the structural units of DNA—on twenty-three pairs of chromosomes are contained in the nucleus of each human cell. If teased apart and laid end to end, the molecules would form an invisible thread nearly six feet long. The information in such a thread, if printed out, would fill 140 Manhattan phone books—and nearby, in three stacks, are exactly that number of them.

In a small theater close to the big DNA model is a five-minute animation loop that explains the uses of genomics in medicine, both to treat disease and to prolong human life. The hope is that in decades to come, as genes that cause various diseases are identified and as ways of removing them or splicing in new ones are perfected, many illnesses will be treated genetically or even prevented altogether. Already the genes for many diseases, from sickle-cell anemia to heart disease, have been pinpointed, though genetic means of treating them are still in their infancy.

Genomic research has raised all sorts of ethical issues, and a number of displays reflect how closely science and ethics are intertwined—not unlike the double helix itself, according to Rob DeSalle, the exhibition's curator as well as codirector of the Museum's Molecular Systematics Laboratory and a curator in the Division of Invertebrates. "Most people would agree that curing disease is a good use of genetics. But what about changing the color of eyes from brown to blue—what we call genetic enhancement? Harmless, per-

haps? But then the next step after that is, 'Well, I'd like my child to be a little smarter than normal.' Or 'Gosh, I'd like her to be able to slam-dunk a basketball.' Before you know it, you're into designer babies. These are ethical questions we'll all face sooner or later."

If you carry the genes for an incurable disease, would you want that information made available to you? To insurance companies? To the government? What about cloning? And would you eat genetically modified corn? Bananas? Salmon? At three computer polling stations in the exhibition, visitors can register their opinions. They can then see how their answers tally with those of people sampled in a Harris Poll.

Genome research also focuses on the concepts of continuity and variation, another pair of intertwining themes incorporated into the displays. Seven percent of our genes are the same as those of *Escherichia coli* bacteria, and we share 90 percent with mice and more than 98 percent with chimpanzees. "This is continuity; the other side of the coin is variation," says DeSalle. "The difference between, say, you and me, is small but it exists: for every thousand base pairs of DNA we share, there's one change, meaning a 0.1 percent difference. There is more variation *within* than *between* racial groups. Humans are 99.9 percent alike—truly a single entity—and that is an important point of the exhibition."

Another point concerns the number of genes in the human genome. This number turns out to be only about one-fourth the initial projection: between 30,000 and 40,000, compared with an earlier estimate of more than 140,000. Fruit flies, by comparison, have between 13,000 and 14,000 genes, and roundworms have 19,000. "The lower number fortifies the whole notion of evolution and of our connectedness with all other organisms," says Michael J. Novacek, the Museum's provost of science.

Ten years ago, the Museum might have been less enthusiastic about mounting an exhibition on genomics, as its traditional mandate has been natural history—the study of organisms at a higher level of complexity than that of the gene. "We care for vast collections and sponsor a hundred expeditions a year, a thousand through a decade," Novacek says. "We wanted to protect all that. Some of us wondered why we should bring molecular biology to a museum, when that kind of work might readily be done at a university. But our mission is to understand the diversity and evolution of life and all the tips of its many branches, so we felt we needed that extra depth of knowledge for a very similar mission: to understand the map of life and the evolutionary process of life."

The Genomic Revolution
The exhibition opens May 26 in Gallery 3 and runs through January 1, 2002.

According to DeSalle, Novacek "led the charge" toward bringing molecular biology into the Museum, though Novacek points out that he was supported by several visionary curators, among them Niles Eldredge, who was already beginning to recruit molecular researchers for the invertebrate department. In 1990 the Museum opened its Molecular Systematics Laboratory, codirected by DeSalle and Ward C. Wheeler. A second molecular laboratory opened in 1995, headed by Joel Cracraft, of the ornithology department. This year, under the management of molecular biologist Bob Hanner, the Ambrose Monell Collection for Molecular and Microbial Research—a repository that will eventually hold 750,000 frozen samples of organic tissue and DNA from a host of species—begins operations.

Now, drawing on the breadth of its research in natural history, its laboratories, and its collections, the Museum is in a strong position to contribute to the field of molecular biology. It has, in fact, been catapulted into the forefront of a new molecular specialty called comparative genomics: the comparison of DNA throughout the animal kingdom.

One goal of comparative genomics is to identify which sequences of genes in the human genome are associated with which traits. "We take a DNA sequence from our genome and search for it in a mouse, a fruit fly, a worm, a nematode, and yeast—all of whose genomes have been either completely sequenced or nearly so. If we locate it in some of them and we identify its function, chances are that the function in the human genome is the same," DeSalle says. "The process is difficult, but it's where the really neat work is going to happen in the near future, and this is where I think the Museum comes in."

Another goal of comparative genomics is to plot evolutionary relationships. Evolution can be tracked back across the eons by comparing genomes and using as yardsticks the similarities and mutations of genes for the same traits in different species—whether the traits are a backbone, two eyes, or four legs. Using molecular biology as well as traditional morphology, Museum scientists can compare and contrast the evidence. The two approaches do not always agree. In the mammalogy department, for example, molecular research projects are causing fur to fly. Morphologists long thought that the primitive mammalian order Monotremata, which includes the platypus, branched off during the Cretaceous Period (between 140 and 70 million years ago). This would make the marsupial and placental mammals—thought to have branched off later—closely related. But molecular evidence now suggests that the marsupials and the monotremes branched off much earlier than the placentals did and that they are therefore the closer relatives.

Following the demise of the dinosaurs at the end of the Cretaceous, there occurred a great radiation—a "star burst," as Novacek calls it—of

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mammals, particularly of placentals, and molecular biology is proving a valuable and controversial tool in finding out what happened. Based on morphology, most mammalogists of the last century agreed that rabbits, for instance, are not closely related to rodents. Today molecular studies at the Museum suggest they are.

For any visitor to the exhibition who wants to know more about the nitty-gritty of DNA—and maybe even have a hands-on experience—a small laboratory near the exit permits people to learn about genetic applications in forensics or even to produce and analyze a sample of their own genes. And on the way out, you walk through a small gallery where your image is picked up on a video camera, processed digitally by computer software, and projected onto the gallery walls—except that instead of the image being formed of pixels, it's made of the letters A, C, G, and T, representing the four basic nucleotides in the DNA molecule. The idea is to produce one image out of the elements of the genome, a graphic expression of its pervasiveness and relevance.

Henry S. F. Cooper Jr., a former staff writer for the New Yorker, *has been visiting the Museum since he was four years old, when his father sat him in a cavity of the Willamette meteorite.*

MUSEUM EVENTS

MAY 1, 8, 15, AND 22

Four lectures: "Genetics and the Brain," neuropsychiatrist Richard Mayeux, May 1; "Learning and Memory," neurobiologist Eric R. Kandel (Nobelist, 2000), May 8; "Development and Cognition," developmental psychobiologist Michael Posner, May 15; "Brain Imagery," neuropsychiatrist David Silbersweig, May 22 (Revolutionizing Medicine in the 21st Century series). 7:00 P.M., IMAX Theater.

MAY 3 AND 10

Two lectures: "Making of Precious Stones," Peter Vreeland, senior Museum instructor, May 3; "Four Wings and a Prayer: Caught in the Mystery of the Monarch Butterfly," entomologist and author Sue Halpern, May 10 (Thursday Afternoons at the Museum series). 3:00 P.M., Linder Theater.

MAY 8

Lecture: "The Eternal Frontier: An Ecological History of North America and Its Peoples." Mammalogist and paleontologist Tim Flannery, director of the South Australian Museum. 7:00 P.M., Kaufmann Theater.

MAY 10

Lecture: "Uncovering the Origins of Dinosaurs in Argentina's Ischigualasto Valley" (Earthwatch at the Museum series). Paleontologist Oscar Alcober. 7:00 P.M., Kaufmann Theater.

MAY 14

Lecture: "The Multiwavelength Universe" (Frontiers in Astrophysics series). Astronomer Alyssa Goodman. 7:30 P.M., Space Theater, Hayden Planetarium.

GEORGE ERML

Bronze African termite mound by sculptor Steve Tobin, on the Museum grounds

MAY 18

Concert: "An Evening with Mary Redhouse." Navajo jazz vocalist. 7:30 P.M., Kaufmann Theater.

Young Naturalist Awards ceremony and luncheon. Noon, Astor Turret.

MAY 21

Lecture: "Time Travel in Einstein's Universe" (Distinguished Authors in Astronomy series). Astronomer Richard Gott. 7:30 P.M., Space Theater, Hayden Planetarium.

MAY 29

Lecture: "Wild Nights: Nature Returns to the City." Science writer Anne Matthews. 7:00 P.M., Kaufmann Theater.

DURING MAY

"Indigenous Peoples: Perspectives and Perceptions." Free weekend programs including films, lectures, performances, and workshops. 1:00-5:00 P.M., Leonhardt People Center and the Linder and Kaufmann Theaters. For information and a complete schedule, call (212) 769-5315.

Musings: The Educators' Connection to the American Museum of Natural History (www.amnh.org/learn/musings/), a free Web newsletter for science educators, is being launched. Published three times a year by the Museum's National Center for Science Literacy, Education, and Technology.

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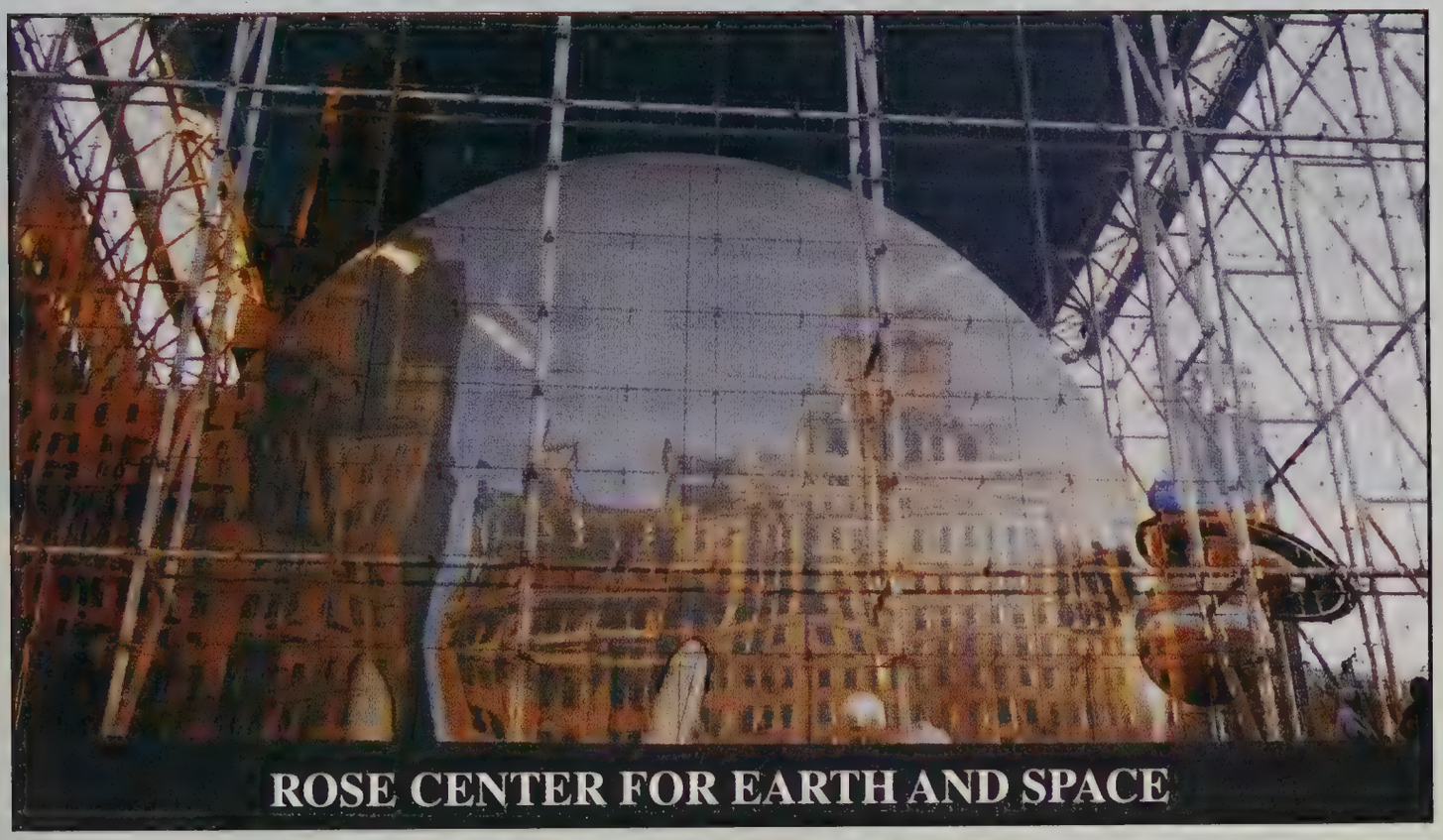

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REVIEW

Most Excellent of Fishes

In the annals of piscine diversity, cichlids break all records.

By Les Kaufman

Almost all living things, even the obscure and distinctly unromantic, have their human enthusiasts. Fleas have their Rothschild; barnacles, their Darwin; and now cichlids, their Barlow. Cichlids are large, tasty, colorful, and endearingly nasty creatures, familiar to fishermen, aquarium hobbyists, and diners worldwide. Never mind that most people seem constitutionally unable to pronounce their name ("sicklids") in any other way than as a brand of chewing gum. Anyone who reads this book will not forget these fishes, in large part due to the narrative skills of the famously cichlid-smitten ethologist George W. Barlow, of the University of California, Berkeley.

Because of their behavior (which makes them seem far more inquisitive and intelligent than most other fishes) and their brilliant, protean garb (which makes them come across as sensitive and emotive to anybody watching them for more than a few seconds), cichlids occupy a place among fish comparable to that of parrots among birds or cephalopods among mollusks. But cichlids' biggest claim to fame is that, individually and collectively, they exhibit legendary diversity in both behavior and appearance. They are, for evolutionary biologists, the maddest of all eruptions out of Santa's workshop. Depending on who's doing the counting, cichlids may turn out to be *th most* diverse of all vertebrate families—or just about. But the difference among them can be subtle, and it take a master to bring them to life on th printed page.

The Cichlid Fishes: Nature's Grand Experiment in Evolution, *by George W. Barlow (Perseus Publishing, 2001; $28)*

In his introduction, Barlow make clear that cichlid hyperbole is not mer hype. Up to 1,000 species of this on family live in a single African lake while only 2,800 species of fishes of a families live in the world's seas, 215 i the freshwater lakes and rivers of Eu rope, and 235 in the immensity of th Laurentian Great Lakes. The first chap ter begins with the best popular ac count yet given of what cichlids are an how they fit into the broad scheme o fish evolution. In th next chapter, "Jaw Two," Barlow tackle with gusto the ric palate of cichlid feedin habits, which are deter mined by the varie shapes and deployments of their jaw and teeth. Chapter 3, "Plastic Sex, leaves behind morphological oral obses sions to examine the realms of sex deter

AD KONINGS

Male firemouth cichlids

mination, sex ratios, sexual domination, and other trappings of sexual conquest.

The bulk of the book is devoted to Barlow's real forte—the events in a cichlid's life history that transpire between parental pairing and the young setting off with bag and pole. Monogamy, sexual subterfuge, mouth brooding, isosexuality (bet you haven't heard *that* term for homosexuality before), and secretocyte ingestion (parental skin cells nibbled off by their fry) are among the many topics that are carefully explained, illustrated, and discussed. Even more intriguing, however, is Barlow's treatment of long-standing myths about cichlid reproduction. Do the egg-shaped spots on the anal fin of some male mouth brooders really make females hot? Barlow's vivid accounts of cichlid family life in all its amazing variants—illustrated by clear, appealing line art throughout—is nonpareil.

In chapter 12, "Cichlid Factories," Barlow discusses how all these cichlid species might have come to be. His overview of speciation hypotheses and cichlid radiations is as good as anything I've seen. Barlow is clearly an adherent of the parsimonious allopatric model (differentiation into separate species because of geographic isolation); proponents of the sympatric model (speciation that is not dependent on geographic isolation) will be disappointed. An endemic species in a tiny sinkhole in South Africa, according to Barlow—and here he refers to one of my own favorites, *Tilapia guinasana*—"may be a window into the process of speciation," because its population of 250 to 400 exists in five distinct color morphs. In the end, however, Barlow says we don't comprehend the basis of cichlid diversity very well. But his "pretty good outline"—a wonderful introduction (for those who might not have spent the last thirty years of their lives obsessing about it) to the whole issue of cichlid species flocks—is about as complete as anybody will be getting for a while.

The book's last chapter, "Fish At Risk," deals with cichlid conservation. It's got diversity, balance, and a good parting shot. That may sound more like a wine than a book chapter, but it has become so formulaic to end books, television shows, and newspaper articles about nature with maudlin stories of anthropogenic destruction that we may as well judge "words in closing" as a genre unto itself. In that context, Barlow has pulled off the end of his book with panache.

Mouth brooding is just one of the behaviors that make cichlid parents so remarkable.

I wish there had been more mention of cichlids in the wild. Most of us temperate-zone Westerners, living where cichlids are notably scarce (except in pet stores and supermarkets), lack the means to hop to the Tropics for a month or two to find out more about them, so we settle instead for nature shows—and indeed, Barlow does mention the spectacular 1996 National Geographic film about cichlids in Lake Tanganyika. Also oddly missing from his account is any detailed treatment of the Texas cichlid *(Cichlasoma cyanoguttatum)*, the only native cichlid in U.S. waters. He mentions the cichlids in warm southern waters only in terms of the evils of human introduction, but these alien fishes can now be observed doing cool things not far from folks' front doors in Florida.

There are a few minor glitches here and there in the text. *Haplochromis elegans* and *Astatotilapia elegans* are referred to as two different species, but P. Humphrey Greenwood's groundbreaking work in the 1960s and 1970s changed that nomenclature. But this is just another illustration of how confusing cichlid taxonomy can be, even to a cichlid biologist. The book itself is attractive and has a nice, old-fashioned heft. It also has a great index, a wonderful and very useful bibliography, and (thank goodness, for many of us) a glossary. And the book is well bound and pretty rugged, as indicated by my copy's capacity to absorb several cups of coffee with only a slight stain on its attractive off-white pages.

In sum, *The Cichlid Fishes* is a marvelous narrative about an extraordinary family of creatures. Barlow's fertile synthesis belongs in the pantheon of natural history classics: G. E. Hutchinson's famous essay "The Cream in the Gooseberry Fool," Konrad Lorenz's *King Solomon's Ring,* Niko Tinbergen's *Curious Naturalists,* and Howard Ensign Evans's *Life on a Little-Known Planet.*

In his Aquatic Conservation and Ecology Laboratory at Boston University, Les Kaufman studies aquatic biological diversity. His favorite workhorses are the labroids, which include cichlids, and for the past dozen years he has analyzed the evolution of fish species flocks in Africa's Great Lakes.

nature.net

Trilobitophilia

By Robert Anderson

For nearly 300 million years, trilobites flourished in the world's oceans. It took the worst mass extinction, at the end of the Permian Period, to stop their long run. Just as dinosaurs and mammals are icons for the following eras, these hard-shelled, crustacean-like animals have come to represent the Paleozoic.

Recently I renewed my childhood fascination with these fossil critters by a visit to the Web site A Guide to the Orders of Trilobites (www.aloha.net/~smgon/ordersoftrilobites.htm), maintained by Sam M. Gon III, a biologist with the Nature Conservancy in Hawaii (a state where, ironically, no fossils have been found, let alone trilobites). An "enthusiastic amateur," Gon studies current biodiversity issues and was drawn to trilobites by their numbers: with more than 15,000 species, they are the most diverse group in the fossil record.

Gon's site is very well done. Offerings on the main menu range from information on the eight orders of trilobites to sections on what the living animals were like. Animations illustrate how they molted and "enrolled" (a term used to describe their defensive posture). Perhaps the most interesting section is "Evolutionary Trends" (click under "Classification"). Trilobites fille a wide range of ecological niches- from free-swimming pelagic feeders t deep-sea, thermal-vent symbionts- and left a remarkably detailed record their transformation from one for to another.

If you find yourself converted into trilobite enthusiast, you might want t try another site, this one maintained b sculptor George W. Hart (www georgehart.com/trilobites/trilobit .html). Here you find a great recipe f edible trilobites. Hart, neither a ga tronome nor a paleontologist, says h just likes the cookies. So do I.

Robert Anderson is a freelance science writ living in Los Angeles.

BOOKSHELF

The Biodiversity Crisis: Losing What Counts, *edited by Michael J. Novacek, $19.95;* **Earth: Inside and Out,** *edited by Edmond A. Mathez, $19.95; and* **Cosmic Horizons: Astronomy at the Cutting Edge,** *edited by Steven Soter and Neil de Grasse Tyson, $24.95 (New Press/American Museum of Natural History, 2001)*

Three books of essays related to the Museum's halls cover such topics as mass global extinctions and how to preserve wildlands (the Hall of Biodiversity), the evolution of continents and mountain ranges (the Gottesman Hall of Planet Earth), and cosmological discoveries and hypotheses (the Rose Center for Earth and Space and the Cullman Hall of the Universe).

Racing the Antelope: What Animals Can Teach Us About Running and Life, *by Bernd Heinrich (HarperCollins, 2001; $23)*

"For millions of years, our ultimate form of locomotion was running," writes zoologist Heinrich, who examines animal physiology and behavior and applies these insights to his own long-distance running.

Evolution's Workshop: God and Science on the Galápagos Islands, *by Edward J. Larson (Basic Books/Perseus, 2001; $27.50)*

"An archipelago of aridities, without inhabitant, history, or hope of either in all time to come," wrote Herman Melville after a visit to the Galápagos in 1841. In Larson's intriguing scientific history, the islands are seen instead as a "field laboratory for the study of evolution in action, their harsh environment an opportunity rather than a curse."

Kids: How Biology and Culture Shape the Way We Raise Our Children, *by Meredith F. Small (Doubleday, 2001; $24.95)*

Anthropologist Small follows the various strands of nature and nurture that determine the fate of our children. Treating us to wide-ranging and informative research about kids in the larger context of human evolution and culture, she also offers astute and lively observations of her own daughter.

Dragon Hunter: Roy Chapman Andrews and the Central Asiatic Expeditions, *by Charles Gallenkamp (Viking, 2001; $29.95)*

This biography of the real-life inspiratio for the fictional Indiana Jones show how a "passionate single-minded ma converted his mad dream of unlockin the secrets of central Asia into a trium phant scientific quest," says Museu paleontologist Michael J. Novacek.

The Energy of Nature, *by E. C. Piel (University of Chicago Press, 2001; $25)*

A mathematical ecologist takes a sy tematic look at the myriad ways i which energy and its transfer affect th earth and its inhabitants.

The Dragon Seekers: How an Extraor dinary Circle of Fossilists Discovere the Dinosaurs and Paved the Way fo Darwin, *by Christopher McGowan (Perse Publishing, 2001; $26)*

The word "dinosaur" was coined b anatomist Richard Owen in 1842. Th and other paleontological "firsts" a chronicled in an engaging book by th senior curator of paleobiology at th Royal Ontario Museum.

The books mentioned are usually avai able in the Museum Shop, (212) 76 5150, or via the Museum's Web sit www.amnh.org.

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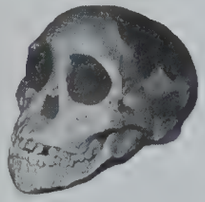

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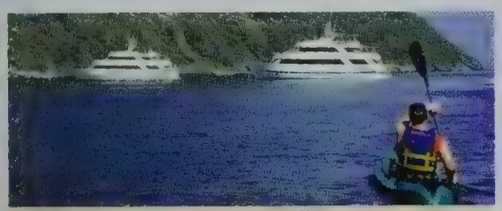

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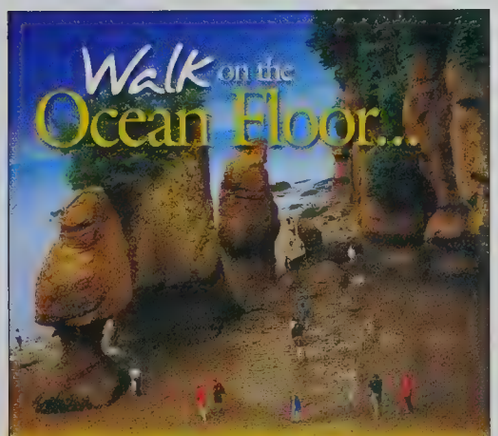

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THE NATURAL MOMENT

Circle of Life

Photograph by John Serrao

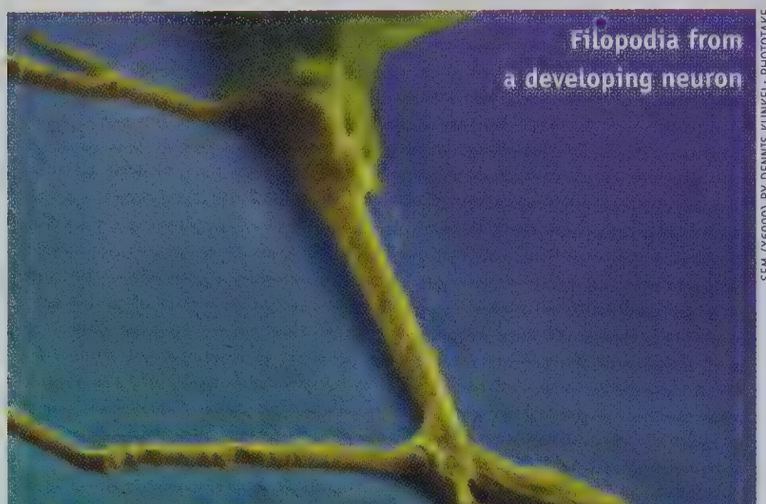
Last July, while strolling through mixed hemlock-hardwood forest in Pennsylvania's Pocono Mountains, photographer John Serrao gently turned over a rotting log. To his delight, he was treated to a rare glimpse of arthropod maternal behavior: a centipede coiled around her eggs.

This brooding female belongs to the scolopendrid family—most common in the Tropics but also found in parts of the United States. Scolopendrids have more than twenty pairs of legs and are usually two to four inches long. Here, what appears to be the centipede's head is really her hind end: she has tucked her head beneath the clutch to make it less vulnerable to enemies.

Centipedes' modified front legs are poison claws, which they use to inject a highly toxic venom. While the small U.S. species prey on worms, insects, and slugs, their foot-long tropical cousins feed on small lizards or mice and can deliver a painful sting to humans.

Scolopendrids reproduce without copulating. The male weaves a silken web on the ground, and in it he deposits a tiny, lemon-shaped spermatophore, or sealed packet of sperm. The female picks up the packet and places it inside her body. Several weeks later, she lays twenty or so eggs and curls herself around them. Fasting for two months, she cares for them intensively and defends them fiercely. She frequently licks the eggs to keep them moist and even coats them with a fungicidal chemical that she secretes from a gland in her head. Without these ministrations, the eggs would become infected with fungi and die. —*Richard Milner*

ENDPAPER



Celle Fantastyk

By Jennifer Ackerman

Once, finding himself bleeding profusely after a bad fall, the naturalist Loren Eiseley apologized to his doomed blood cells: "Oh, don't go. I'm sorry." The words were spoken to no one, he wrote, but addressed to all the "crawling, living, independent" entities that had been part of him, and now, through his "folly and lack of care, were dying like beached fish on the hot pavement."

I'm not sure I could summon such compassion for my individual cells, not sure I could think of them as creatures with a wit and wisdom of their own. Just as a single molecule of H_2O doesn't make water, a single cell from the brain of a mouse sliding over its petri dish contains no thought; only when the cell links up with millions of others in an electrochemical network does thought emerge.

Still, Eiseley was on the right track.

One afternoon not long ago, I watched a film of what looked for all the world like a little squid thrusting forward a slender foot, as if to test the possibility of moving in one direction. Then the little creature slowly pulled back the foot, paused for a moment, and sprouted a new foot. This thin, twitching new limb poked out in a different direction, again searching like a tongue or antenna.

But all was not as it appeared in the film. Neither time nor scale was real. It was time-lapse video microscopy, with the small made large beneath a high-power lens, and hours squeezed into seconds—the same kind of compressed-tim photography that makes clouds boil across the sky and th tendrils of a growing vine snake around the trellis. Acceler ated or not, the movement of the little beast looked willfu no mere amoebic slithering or crawling about, but a deli cate, precise, silvery motion invested with intelligence.

The star of the film—made by Diane Hoffman-Kim, cell biologist then at Harvard—was no mollusk but th amoeba-like growth cone at the tip of an axon, a slende fiber that extends from a nerve cell—this one isolated fro the spinal cord of a chick embryo. The "feet" were filopo dia, Hoffman-Kim told me, dynamic little extensions of th cell membrane thrusting out from the growth cone, th leading edge of a growing axon, which the cell uses to sni out connections with other nerve cells.

Hoffman-Kim was studying the way cells find one an other to create the netted wiring of the brain, not just dur ing embryonic development but all through life as the bod learns new skills. She was interested in the molecules outsid the cell that steer the tentative axon to its quarry, telling where to go as it tunnels through tissues, in this direction o that. Once it finds exactly the right cell to hook up with, link is formed. Somehow the cell initiates the connectio and is itself altered by its accomplishment. If a skill is use again and again, the link hardens; if it's used only once, th filopodia soon shrink back, triggering a change in the brai cell, a thinning of the grip that may explain forgetting.

I was fascinated by the disembodied cell itself, whic seemed to act as its own creature. On the scale of biologica complexity, a single cell is said to occupy a spot roughl midway between the microcosmic world of genes and pro teins and the visible world of the organism. My cells ma have subsumed their individual identity by joining a large community, but each still has its independent existence an contains a similar, if simpler, version of the mystery hidde in my head. Each is an immensely competent being, holdin my whole genome, capable of subtle movement, rhythm and sophisticated talk, adept at sucking energy out of life and—when sufficiently full of zip—doubling and redou bling to make the world a fecund place.

Who's to say that each does not enjoy its own life?

Jennifer Ackerman's Chance in the House of Fate: A Natura History of Heredity *will be published in June by Houghton Mi flin. Her previous book is* Notes From the Shore *(Viking Pen guin, 1995).*

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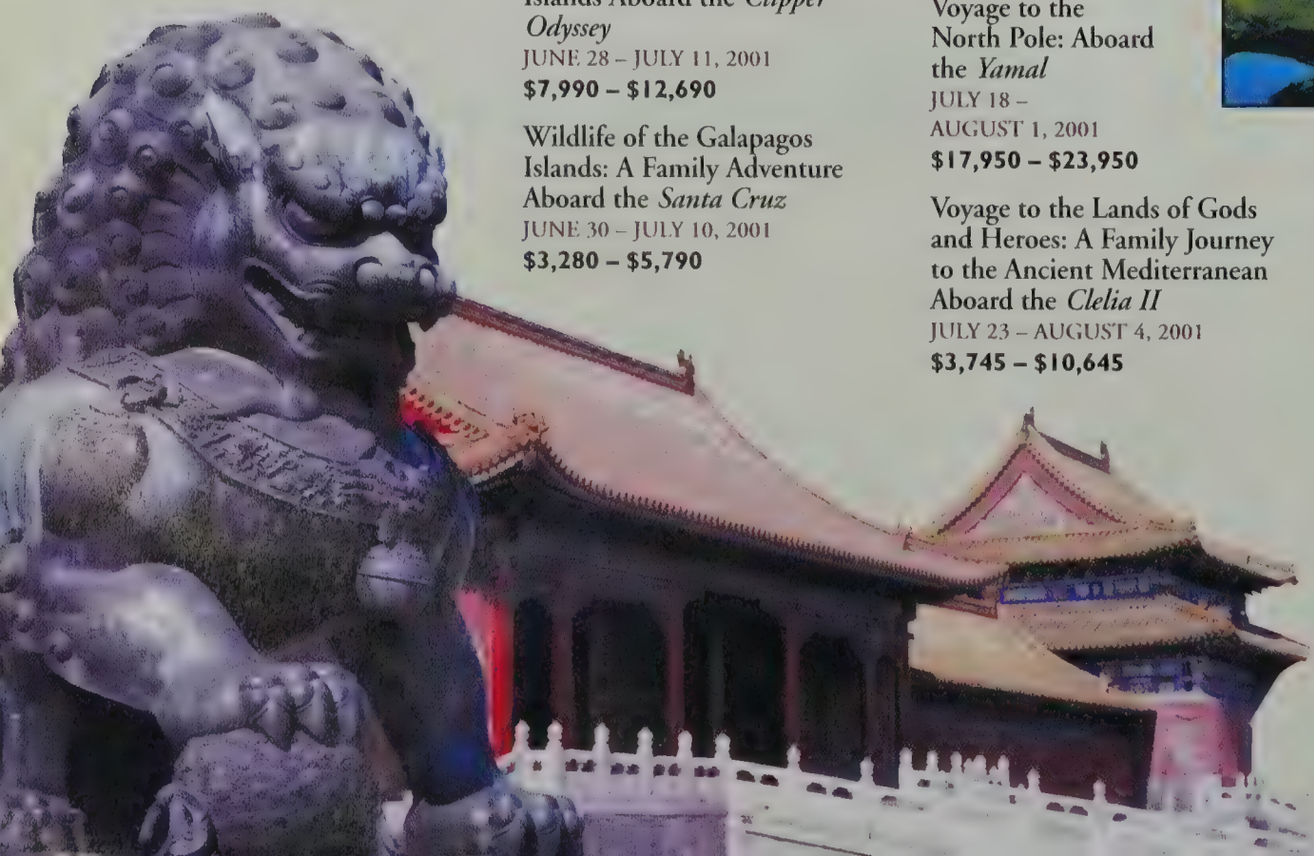

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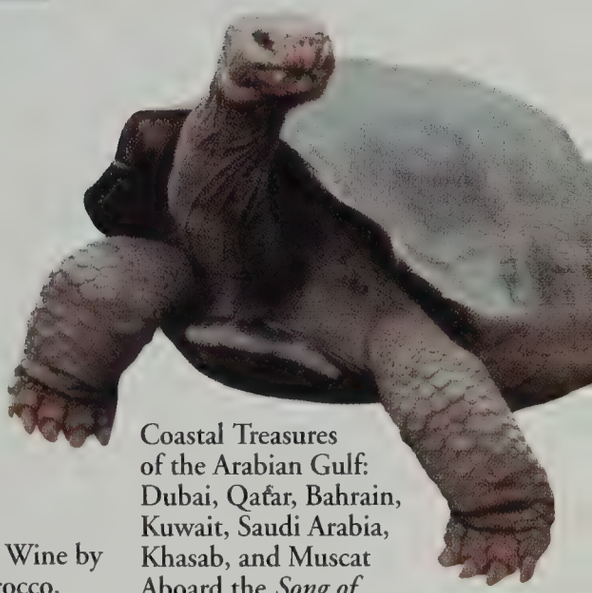

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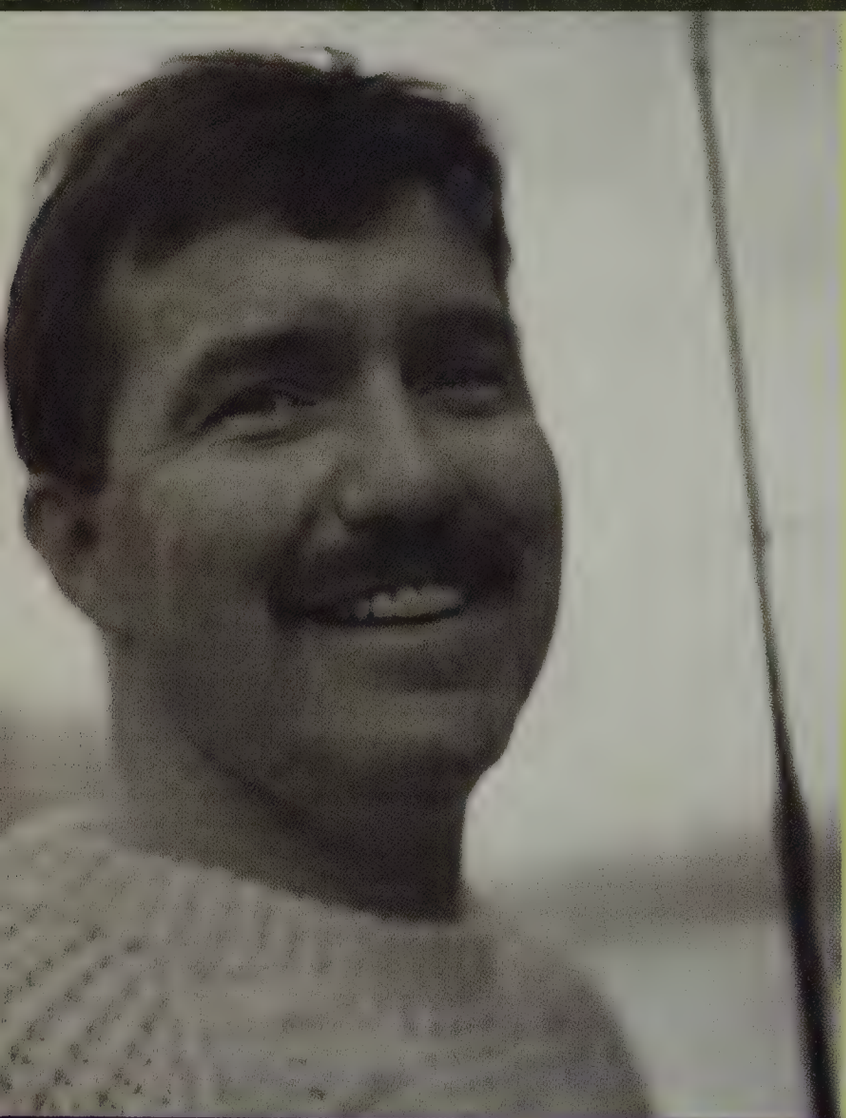

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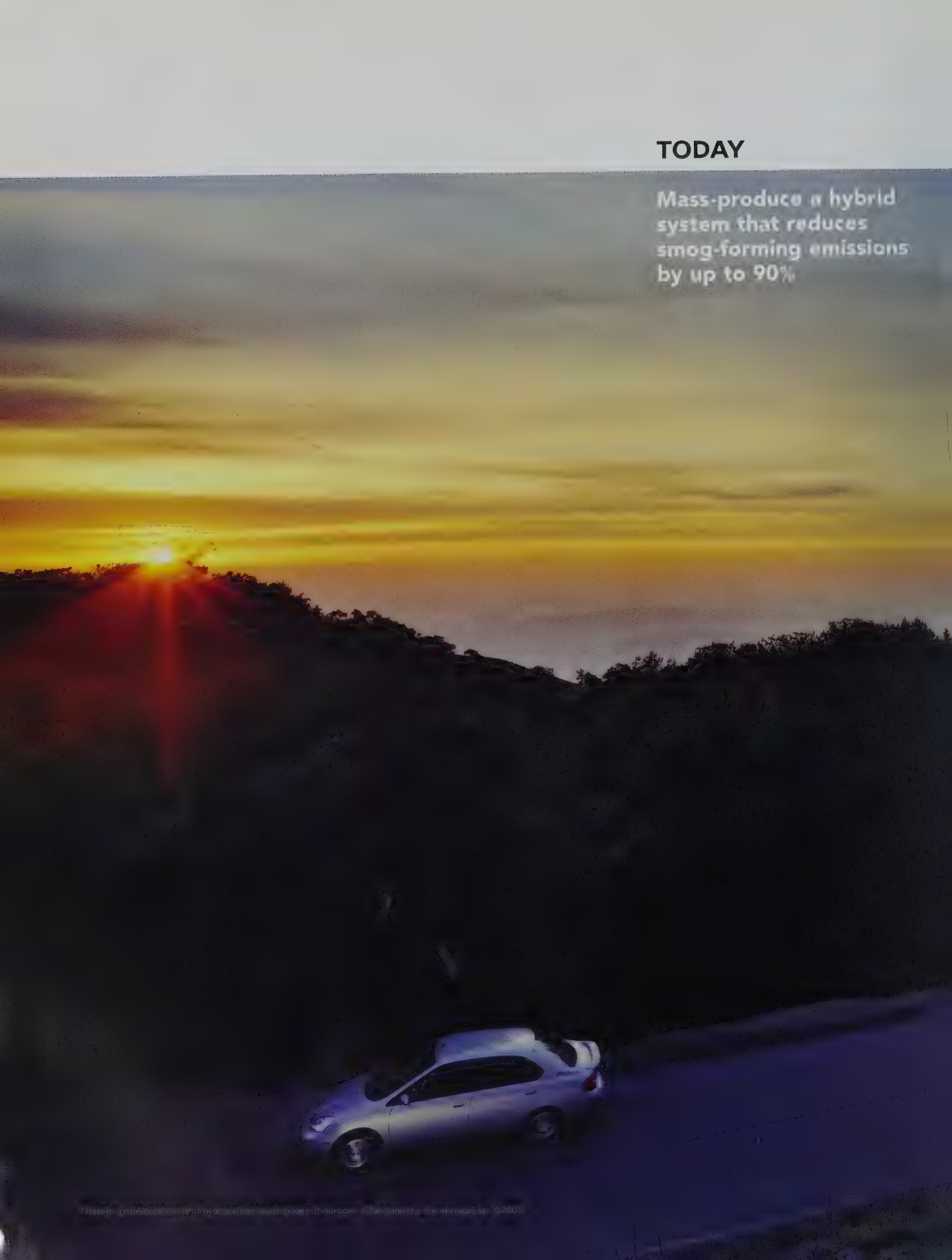

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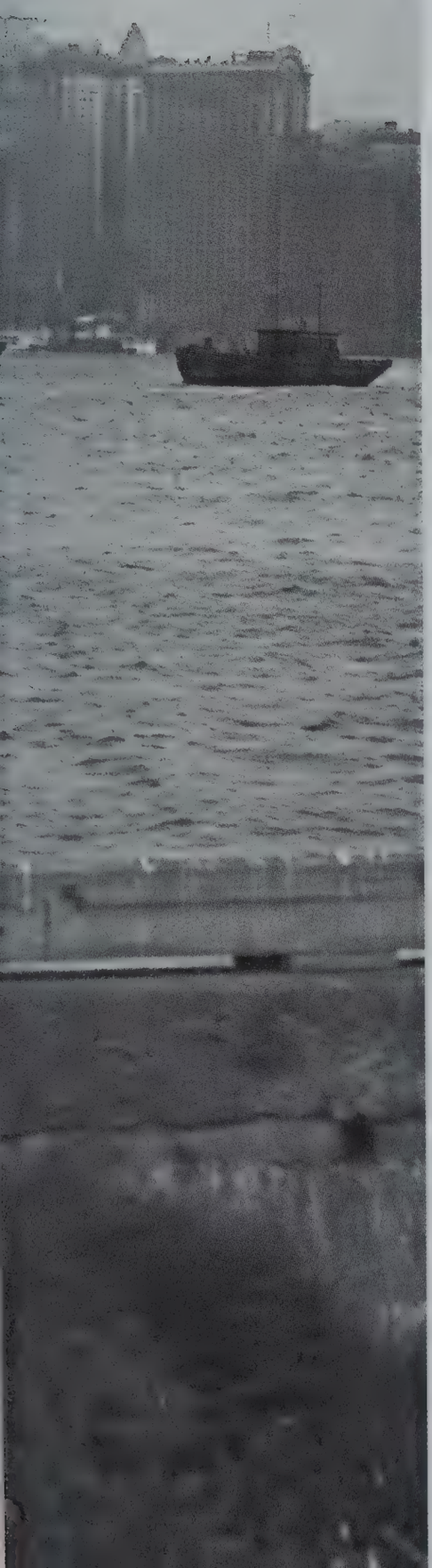

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JUNE 2001 VOLUME 110 NUMBER 5

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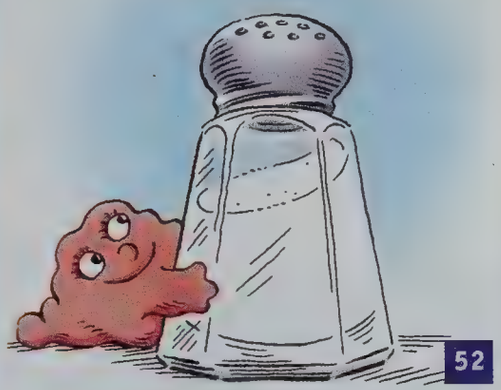

OF GENES AND GENOMES

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MARK RIDLEY

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ROBERTA FRIEDMAN

COVER Our bodies have two kinds of genomes. The larger one (recently sequenced) is found in the center of each of our cells. But a different set of genes, of bacterial ancestry, dwells in the mitochondria, the cells' powerhouses. Our innards and skin also host hundreds of microbial species, each with its own genome. Artist **Alexis Rockman** adds mitochondria (green ovals) and bacteria (spirals and rods) to a fanciful "portrait" of our species.

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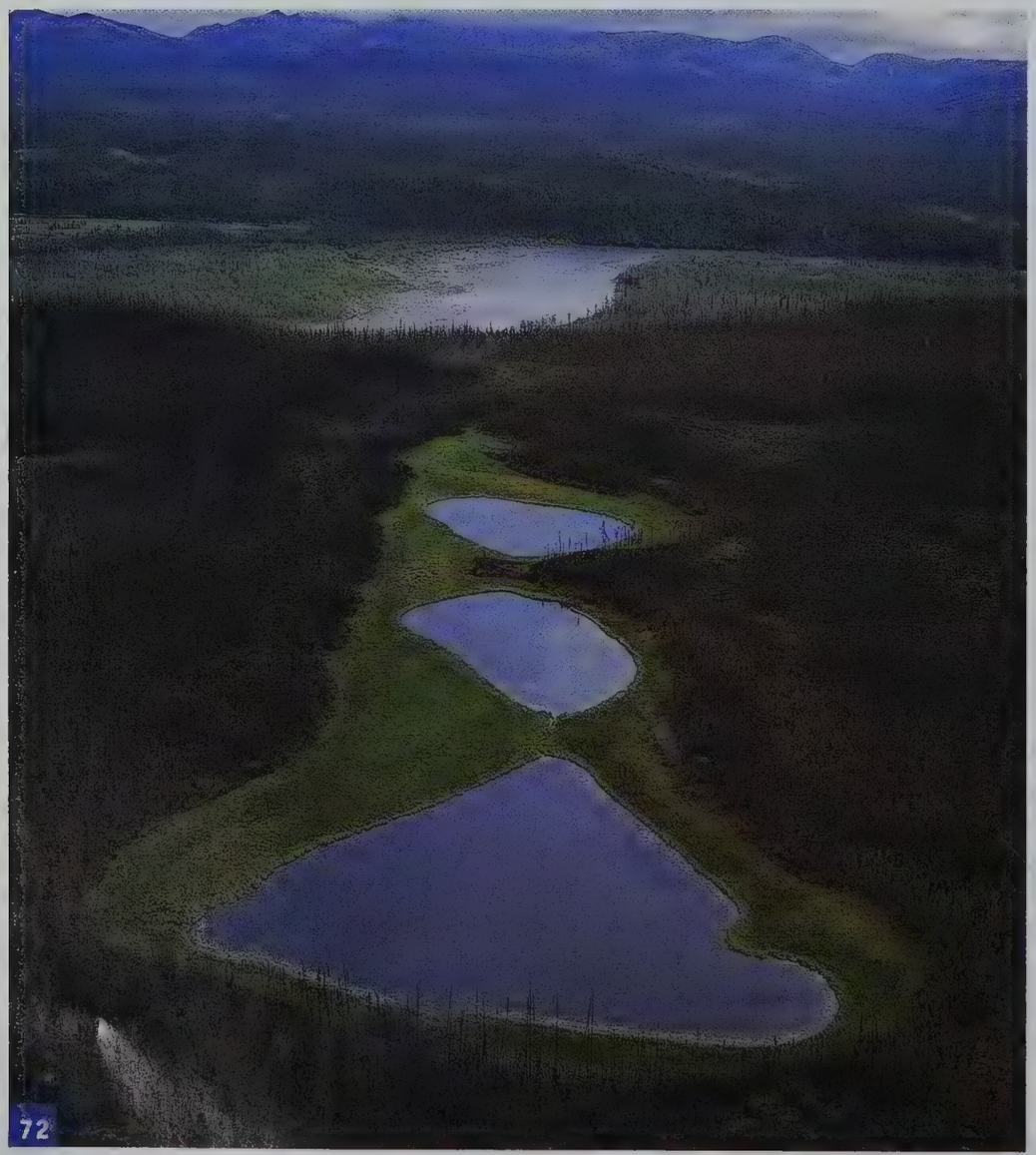
A sampler of various and versatile snouts
LAWRENCE M. WITMER

BORN TO BE TAME
Trusting, hand-raised birds go to desert survival school.
YOLANDA VAN HEEZIK AND PHILIP SEDDON



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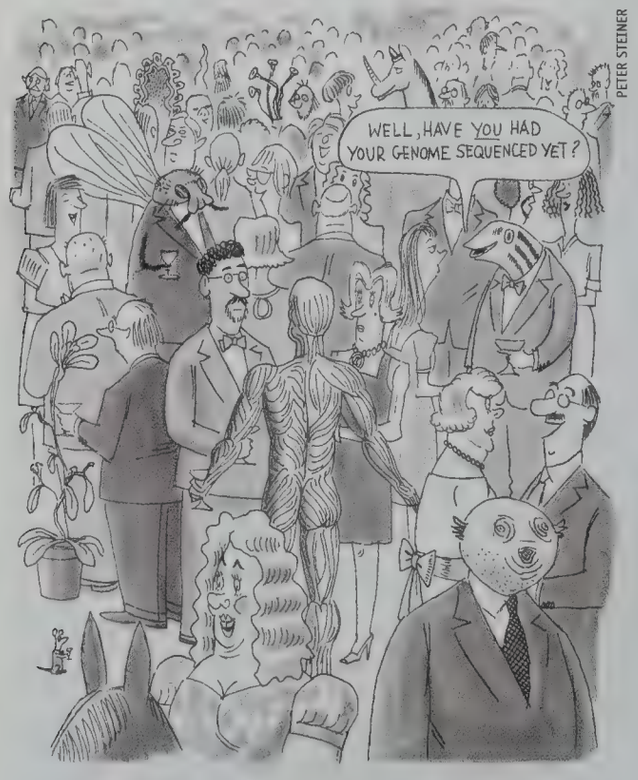
UP FRONT

Lifestyles of the Small and Obscure

Science, a product of the human mind, has delivered repeated blows to the human ego. Copernicus removed us from the center of the solar system. Darwin displaced us from near-angelic status by sticking us on a quite ordinary, though relatively new and green, branch of the animal family tree. Edwin Hubble informed us that the Milky Way is an undistinguished galaxy in a nondescript corner of the universe. Then came the Human Genome Project. When a draft of our genome was published in February of this year, we learned that we don't even have as many genes as we thought we did. The estimated 100,000 was pared down to a mere 33,000—not all that much bigger than the genome of a mouse (28,000), a fruit fly (23,000), or a nematode (22,000). Of course, numbers aren't everything, but these findings do bruise our vanity.



So far, gene-sequencing professionals have devoted most of their attention to bacteria, whose genomes typically have between 1,500 and 4,000 genes. And as the most abundant (and arguably the most influential) organisms on Earth, bacteria deserve the limelight. About 2 billion years ago, they made complex life possible by getting themselves incorporated into larger cells and going on to do the jobs of respiration and photosynthesis in animals and plants. (Plants and animals, including humans, still carry bacterial descendants in each cell, as Lynn Margulis and Dorion Sagan explain in "The Beast With Five Genomes," page 38.)

Genomic studies can tell us something about how bacteria behave in human bodies and other habitats. Turn to "Bacterial Revelations" (page 52) for new insights into the obscure lifestyles of several germs—including the tuberculosis bacillus, the typhus pathogen, and the sea-dwelling *Prochlorococcus marinus,* the world's smallest and most common photosynthetic bacterium.—*Ellen Goldensohn*

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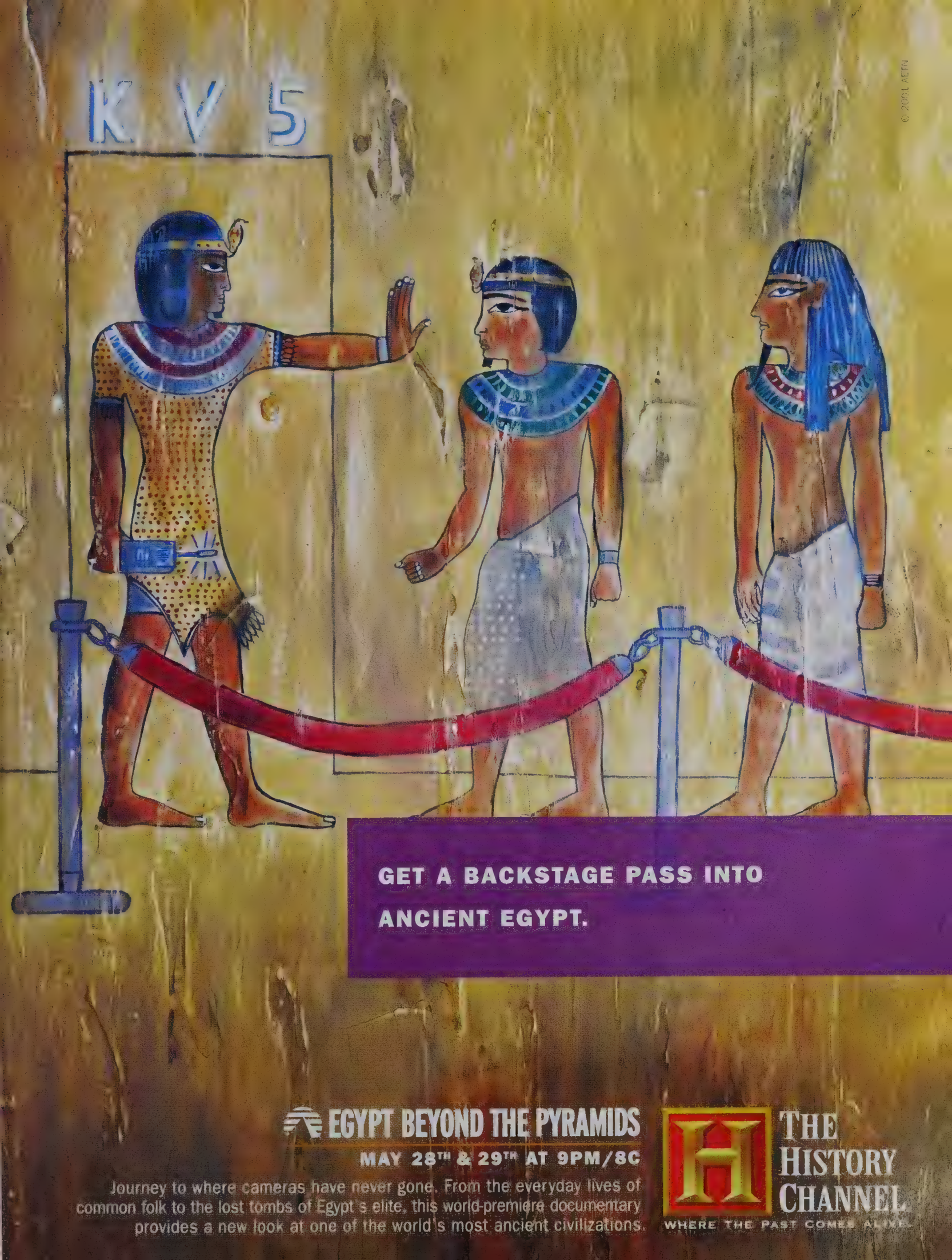
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LETTERS

O Pioneers!

"The Scavenging of 'Peking Man,'" by Noel T. Boaz and Russell L. Ciochon (3/01), was fascinating. However, Helmuth Zapfe's studies on cow bones fed to captive hyenas were not, as the article states, pioneering. William Buckland, the first professor of geology at the University of Oxford, conducted the same experiments in Oxford in 1821 by feeding ox bones to a hyena in a traveling menagerie. He compared the fragmented bones with bones found in various caves in England, which he interpreted as having been ancient hyena dens—at the time, a most controversial view. Buckland published detailed comparative engravings of the bones. His work and experimental approach were truly pioneering.

Neville Haile
Oxford, England

Heaven . . .

Could authors Scott L. Wing ("Hot Times in the Bighorn Basin," 4/01) and Kenneth D. Rose ("Wyoming's Garden of Eden," 4/01) be a little more specific as to where in the Bighorn Basin their studies take place? The basin is paleontology heaven, with excellent outcroppings of everything from Precambrian to Tertiary age in the Wind River Canyon, at the southernmost part of the basin, to huge dinosaur finds in Thermopolis and outstanding petroglyphs at Cottonwood Creek near Hamilton Dome.

Steve Leece
Baguio City, Philippines

SCOTT WING REPLIES: "Paleontology heaven" is the best two-word description I have heard for the Bighorn Basin. The Paleocene and Eocene fossils and rocks that we study are near Cody and other towns in the central portion of the basin. Within that area are literally thousands of fossil locations. Almost all of these are away from major rivers, dry creeks, and sagebrush flats, where recent sediments tend to cover the older rocks.

. . . and Hell

Scott Wing matter-of-factly writes of the Eocene global warming as being "perhaps as rapid as the one we humans are about to cause and experience." I don't believe there is enough evidence to support such a strong indictment of humanity. There have been many other documented ice ages in the last 100,000 years and rapid warming and cooling spells in the interglacial periods. The fact is that little, if anything, is known about what causes climatic change on a large scale. To blame humanity is harsh and premature.

Kent K. Smith
via e-mail

SCOTT WING REPLIES: Kent Smith correctly states that rapid climate change has occurred in the absence of human activity. That was what my article was about, so I clearly do not "blame humanity" for all climate change. That said, the addition of CO_2 and other greenhouse gases to the atmosphere through human activities is well measured and documented, and I am not aware of any scientists who dispute that these gases lead to an increase in temperature near the earth's surface. The exact amount of warming that will be generated, the possible role

KENNETH D. ROSE

of countervailing factors, and the effects of climate change on plants and animals are poorly understood at present. That's one reason why research into the history of climate change is important and why working on these problems is prudent planet management—the business we humans are getting into, whether we admit it or not.

Interesting Point

Steven N. Austad's review of *The Quest for Immortality: Science at the Frontiers of Aging*, by S. Jay Olshansky and Bruce A. Carnes (4/01), does a good job of highlighting the two sides of the anti-aging debate, but his description of a bet with Olshansky overstates the miracle of compounding. The author reckons that their $300 bet will have become $500 million in the year 2150. Not likely. Eight percent rather than 10 percent annual interest is probably more realistic, and that yields a more modest figure of $30 million. Figuring in 3 percent inflation, we wind up with a much less impressive $450,000 at the end of those 150 years.

Stuart Robinson
via e-mail

STEVEN AUSTAD REPLIES: The miracle of compound interest is pretty evident, given that a mere 2 percent difference in our interest-rate assumptions leads to Stuart Robinson's calculation of my wager as yielding a mere $30 million, compared with my estimate of $500 million (or more than $7 *billion* if the interest rate is 2 percent higher). I trust that my guess, using seventy years of history as a guide, has as much credibility as Robinson's—that is, very little. Regardless of inflation, $30 million or $500 million or $7 billion ought to at least buy my descendants a good night on the town to celebrate their farsighted ancestor.

Natural History's e-mail address is nhmag@amnh.org.

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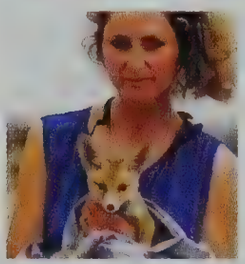
CONTRIBUTORS

As a graduate student in genetics at the University of Wisconsin, **Lynn Margulis** ("The Beast With Five Genomes," page 38) learned about "cytoplasmic genes"—such as those that determine green color in plants—and recognized that they belonged to microbes that were once free living. Now a Distinguished University Professor at the University of Massachusetts Amherst, she is still exploring the implications of such ancient mergers. Margulis has collaborated with writer **Dorion Sagan** on numerous books, including *Slanted Truths: Essays on Gaia, Symbiosis and Evolution* (Springer-Verlag, 2001). Their collaborative work is accessible at www.sciencewriters.org. Sagan is now coauthoring a book on the evolution of intelligence.

Mark Ridley ("Sex, Errors, and the Genome," page 42) started gravitating toward a career in the natural sciences in his midteens, after hearing a lecture by famed marine biologist Alistair Hardy. Ridley's fascination with genes and evolution developed at the University of Oxford, where he first encountered the ideas of Richard Dawkins. Now himself a researcher in Oxford's zoology department, Ridley is the author of several books, including *The Cooperative Gene* (Free Press, 2001). Despite his penchant for theory, Ridley still enjoys old-fashioned natural-history pursuits such as identifying birds, bugs, and flowers.

Roberta Friedman ("Bacterial Revelations," page 52) grew up in Queens, New York City. She received her Ph.D. in pharmacology from Vanderbilt University in Tennessee, where she researched the neurotransmitter serotonin, but realized that she much preferred writing about research to carrying it out. For the past fifteen years, she has written on science and medicine for a variety of publications. A resident of Santa Cruz, California, Friedman has also written on science for children, inspired lately by her three boys. Now ready for a third career, she makes pottery and hopes to set up her own studio soon.



Yolanda van Heezik and **Philip Seddon** ("Born to Be Tame," page 58), coauthors and spouses, spent nine years at the National Wildlife Research Center in Taif, Saudi Arabia, helping to reintroduce houbara bustards into the desert. The pair met at the University of Otago in New Zealand, where both did their doctoral work. They wrote about jackass penguins in South Africa for the November 1997 issue of *Natural History.* Now back in New Zealand with their four-year-old son, Connor, Heezik (left) is a lecturer in zoology and Seddon (see page 61) is director of the wildlife management program at the University of Otago. Sophie the fox now lives "in a state-of-the-art captive breeding facility in the United Arab Emirates and may soon embark on a new career as a mother."

Associate professor of anatomy at the Ohio University College of Osteopathic Medicine in Athens, **Lawrence M. Witmer** ("A Nose for All Reasons," page 64) has "one foot in the Mesozoic and the other in the present, studying living species to learn about dinosaurs and other extinct beasts." To that end, he has made CAT scans of everything from tapirs to *Allosaurus* and, with his students, dissected all sorts of animals (currently in the freezer are two rhinoceros heads, two manatee heads, monitor lizards, seals, and birds). To colleagues who complain about the odor coming from his lab, he replies, "Sometimes science stinks."

After two decades of traveling on assignment for *National Geographic,* photographer **Jim Brandenburg** ("The Natural Moment," page 84) decided to settle down next to a million-acre wilderness in his native Minnesota. Coming upon the tracks of a wolf or a lynx gives him even more pleasure, he reports, than did his former adventures in the Namib Desert or the forests of Manchuria. Brandenburg's books include *White Wolf: Living With an Arctic Legend* (Northword Press). He has established a nonprofit gallery of his work in his hometown of Luverne; the proceeds go to acquiring and preserving the tallgrass prairie near his boyhood farm there (see www.jimbrandenburg.com).

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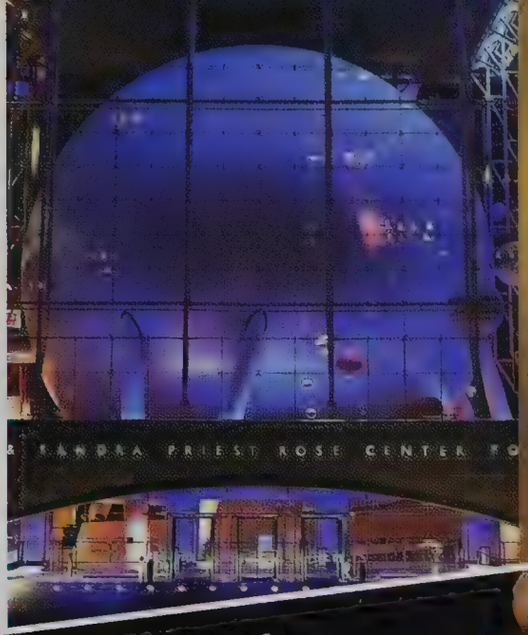

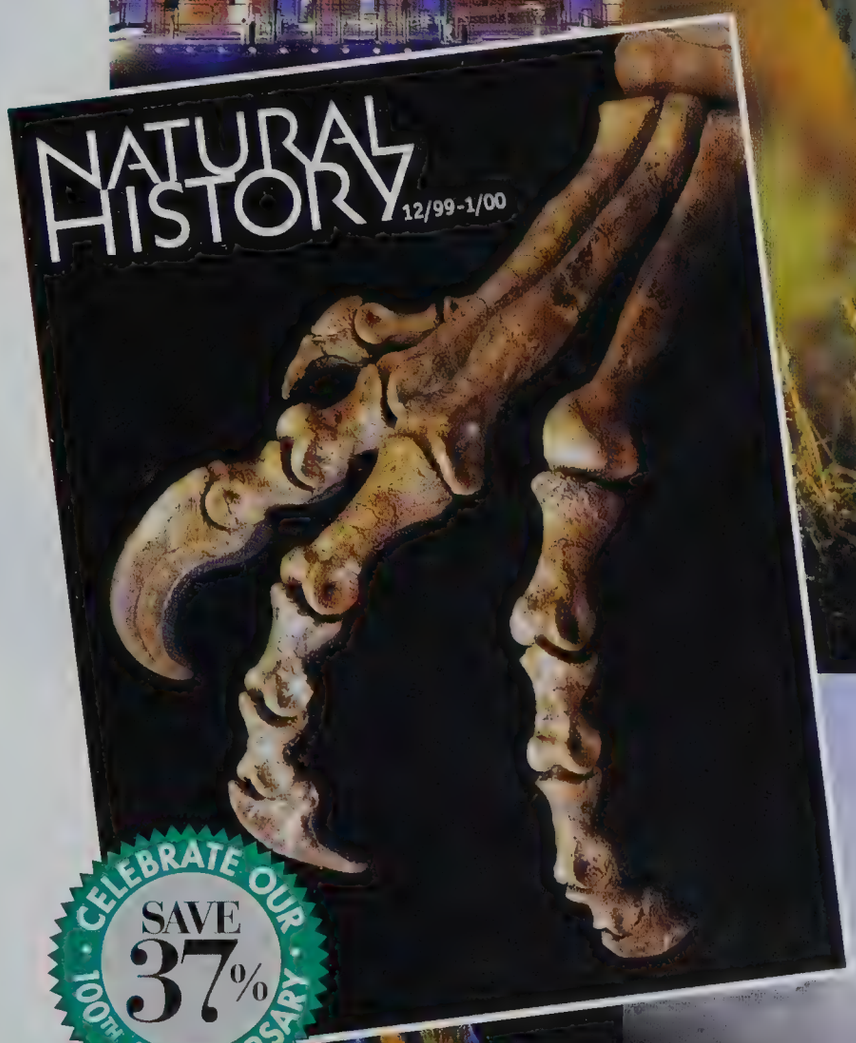

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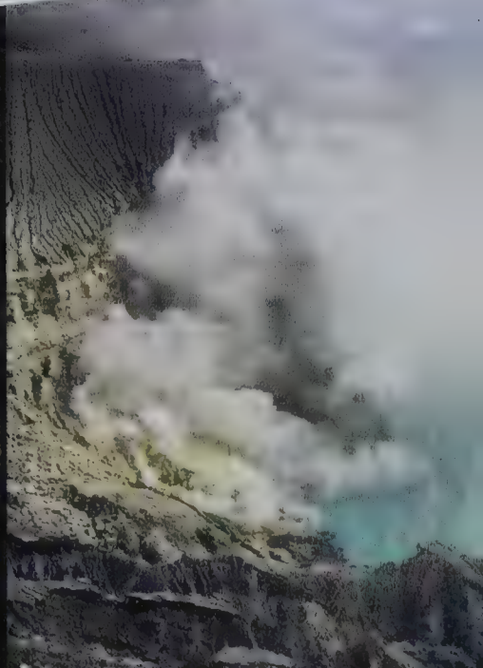

FINDINGS

THE CHIMERIC SELF

Cellular traffic between mother and fetus raises questions about the causes of autoimmune disease.

By J. Lee Nelson

One of the unsolved mysteries of immunology is why the body of a pregnant woman doesn't reject her fetus. After all, our immune system evolved to keep foreigners out, to maintain a clear distinction between self and other. In recent years, the mystery deepened as researchers learned that fetal cells get into the maternal bloodstream during pregnancy and, what's more, may stay there for decades, perhaps indefinitely. What might this mean for how we think about autoimmune disease?

The traditional view of autoimmunity is that it is a case of mistaken identity: a body, often for no apparent reason, fails to recognize some of its own tissues and mounts an attack against itself. There is no evidence, for example, that rheumatoid arthritis sufferers had anything wrong with their joints, or with the tissues lining the joints, that might have led to the onset of the disease; their bodies appear to have simply turned on themselves. The indefinite persistence of fetal cells in a woman's body, however, led me to ask if some so-called autoimmune diseases may be triggered by foreign cells, specifically by fetal cells present in the mother's body. After several years of looking into this question, I recently proposed that what we may be dealing with, in fact, is a kind of chimerism, though on a microscopic scale.

In Greek mythology, the chimera was a fire-breathing creature with the head of a lion, the body of a goat, and the tail of a serpent. In modern medicine, the term "chimerism" refers to an organism whose body contains populations of cells derived from another individual—a less grand but, to researchers like myself, equally compelling notion. Microchimerism is said to exist when the number of nonhost cells is very low (for example, fewer than one foreign cell for every million host cells).

One observation that led me to suggest a connection between microchimerism and autoimmune diseases was that these illnesses—among the most familiar of which are rheumatoid arthritis, systemic lupus erythematosus, and multiple sclerosis—usually afflict

ARCHAEOLOGICAL MUSEUM, FLORENCE; SCALA/ART RESOURCE, NY

rezzo chimera, bronze, sixth century B.C.

more women than men, sometimes at ratios of greater than ten to one. Furthermore, many of these diseases strike most often in late middle age. Three such examples are thyroiditis (an inflammation of the thyroid gland), primary biliary cirrhosis (inflammation and destruction of the liver), and scleroderma (progressive hardening of the skin and internal organs). If these diseases hit earlier in life, when hormonal differences between men and women are so striking, the logical assumption would be that sex hormones were somehow implicated. But in part because they tend to come on later in life (often not developing until after menopause), I looked for other differences between males and females. Pregnancy was an obvious one, and I was intrigued by the possibility that women are uniquely subject to a kind of reverse inheritance from their children.

Men and children, as well as women who have never been pregnant, also develop autoimmune diseases, but microchimerism could play a role in these populations as well, because there are several ways people may wind up, perhaps indefinitely, with cells that aren't their own. During pregnancy, for instance, the mother's cells can also pass into the developing fetus. In addition, cell transfer can occur between twins in utero. Blood transfusions are another pathway for cell transfer: although the donor's red blood cells—which have no nucleus and are short-lived—are soon cleared from the recipient's circulation, it turns out that the donor's longer-lived, nucleated white blood cells can persist within the recipient.

Further sparking my interest was the knowledge that leukemia and lymphoma patients who undergo bone marrow (stem cell) transplantation often develop a syndrome known as chronic graft-versus-host disease, with symptoms very much like those of certain autoimmune diseases, especially those of scleroderma. This syndrome occurs most often when the donor's cells are not perfectly matched to the recipient's.

Much of my own research—done in collaboration with colleagues at the Fred Hutchinson Cancer Research Center in Seattle and with Diana Bianchi and her team at the New England Medical Center in Boston—has focused on scleroderma. This insidious illness begins with hardening of the skin on the fingers and toes and slowly marches to the arms, legs, face, and trunk. Advanced hardening can result in skin ulcers and the loss of fingers or toes. No treatment exists to reverse scleroderma, and when it moves to the digestive system, kidneys, heart, and lungs, it is often fatal.

To investigate the possible role of microchimerism in scleroderma, we took blood samples from two groups of women: scleroderma patients and healthy "controls." All the women had previously given birth to a son (mothers of sons were chosen because of the availability of a simple test to detect male DNA in a female host). We found that the amount of male DNA in a tablespoon of blood was significantly greater in the scleroderma patients—equivalent to as many as sixty-one male cells, compared with a maximum of two in the healthy women. The women in our studies had borne their sons many years earlier, yet the levels of male DNA in some of the scleroderma patients exceeded those found in pregnant women carrying a normal male fetus. Working with skin biopsy samples, other investigators subsequently produced similar results.

As exciting as these results were, the mere presence of foreign DNA is not sufficient to explain scleroderma. By using very sensitive techniques, we were able to detect fetal cells in the immune systems of more than 60 percent of the healthy women we tested—present in smaller numbers than in the sick women, but there nonetheless. Why, then, do I think that such cells may be implicated in some instances of disease but not others?

The answer, I believe, lies in the genetic relationship between a mother and her child, specifically in how closely matched their *HLA* genes are. Present in almost all the nucleated cells in our body, *HLA* genes are a crucial part of our immune system, vital to the body's ability to distinguish self from other. A clear mismatch between the *HLA* genes of a pregnant woman and her fetus appears to be a good thing, because the mother's immune system will then have no trouble recognizing as foreign any fetal cells that may cross over into her bloodstream. If maternal and fetal *HLA* genes are a perfect match, cell movements from one to the other will also not be a problem, since there would in

fact be nothing foreign to worry about. But what if, my colleagues and I wondered, the *HLA* genes of mother and child are not identical but very similar? Might this make it easier for the foreign cells to slip past the mother's immune system undetected and remain active? If so, might this somehow put the mother at risk of developing an autoimmune disease later in life?

To find out, we looked at the *HLA* genes of women with scleroderma and those of their children. Such studies can be confusing because of the many variations on the theme of matched and mismatched genes. "Foreignness" quickly becomes a matter of perspective. For illustration's sake, imagine a mother who has *HLA* genes *A* and *B* and a father who has *A* and *C* (in reality, of course, many more genes than this are involved). If both the mother and the father happen to pass on the *A* gene, then the fetus—with its two *A* genes—will not seem foreign to the mother, who has an *A* gene of her own. From the point of view of the fetus, however, the mother's *HLA B* gene will register as foreign.

In this study, we concentrated on *HLA-DRB1,* a gene known to be involved in scleroderma and in many other autoimmune illnesses. What we found was striking: scleroderma patients were nine times more likely than were healthy mothers to have given birth to a child whose *HLA-DRB1* genes were very similar to theirs. And when, as in the hypothetical example above, foreignness existed only from the perspective of the child, the mother then appeared to run as much as a nineteen-fold risk of developing this devastating disease.

Fetal cells and fetal DNA have been found by researchers investigating other autoimmune diseases as well—for example, according to one preliminary report, in the salivary glands of some patients with Sjögren's, or sicca, syndrome (in which inflammation results in dry eyes and a dry mouth) and in the livers of patients with primary biliary cirrhosis (although, complicating matters, it was also frequently found in the livers of patients with other non-autoimmune diseases). Furthermore, two recent papers on myositis, a degenerative muscle condition, reported finding more maternal cells in children with this disease than in those without. Our scleroderma team has detected maternal cells in adult children, some of whom were scleroderma sufferers and others not. Other researchers have found they could induce lupus in laboratory mice by injecting parental cells into offspring, suggesting that maternal cells could be involved in this disease as well.

Women are uniquely subject to a kind of reverse inheritance from their children.

If foreign cells are indeed involved in autoimmune disease, why is there often such a long lag between the time of cellular transfer and the onset of illness? The most likely explanation is that these cells may, under the right genetic circumstances, predispose a person to an illness, but that some kind of triggering event—exposure to an infectious agent, for example, or an environmental toxin—must also occur in order for the disease to develop.

At this stage, we don't yet know *how* one person's cells cause malfunctions in the body of another. We think it less likely that damage results from a direct attack on host tissues than that the foreign cells operate like a computer virus, disrupting the sensitive network of communication between cells responsible for immune regulation in the body of the host.

The study of microchimerism in human health and disease is a new frontier. My research has convinced me that the movement of cells from one individual to another will prove to be an important factor in at least some diseases. There are, however, other interesting (and not mutually exclusive) possibilities. Persistent foreign cells—whether fetal or maternal—may sometimes be neither detrimental nor neutral, but beneficial. Some studies, for instance, have suggested that once a woman has given birth, she may in fact have a reduced risk of developing rheumatoid arthritis, and we are currently investigating the possibility that reverse inheritance may be providing some protection here. And we have found that when fetal and maternal cells are genetically mismatched in a particular way, a woman who already has rheumatoid arthritis may sometimes enjoy remission from the disease during her pregnancy.

Future research will undoubtedly reveal much more about the cellular traffic between mother and fetus, including whether this form of microchimerism is simply an unavoidable side effect of pregnancy or whether—if beneficial effects should prove to outweigh the negative ones—it might actually have been the target of natural selection. Obstetricians may never feel the need to hand out pamphlets entitled "Warning: The genes you don't inherit may be harmful to your health." But one thing is certain: microchimerism research has shed new light on the age-old question "Who am I?"

J. Lee Nelson is an associate member in the Program of Human Immunogenetics at the Fred Hutchinson Cancer Research Center and an associate professor in the Division of Rheumatology of the University of Washington, Seattle.

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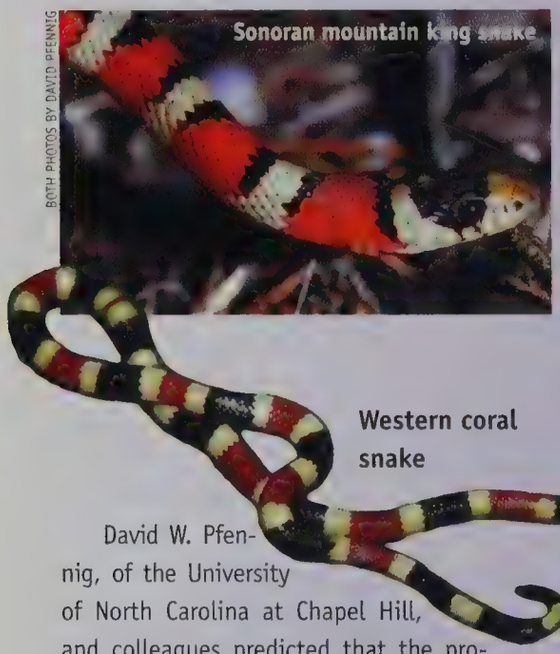
IN SUM

SNAKY FAKERY According to a theory of mimicry promulgated by English Victorian naturalist Henry Walter Bates, some harmless creatures warn away predators by evolving a strong resemblance to poisonous ones. Thus, several kinds of king snakes mimic the venomous coral snake's distinctive pattern of alternating red, black, and yellow or white bands. Now an experimental field study has demonstrated that the king snakes can get away with the charade only if coral snakes inhabit the same locality.

BOTH PHOTOS BY DAVID PFENNIG



David W. Pfennig, of the University of North Carolina at Chapel Hill, and colleagues predicted that the protective effect of looking like a coral snake would break down in areas where the genuine article was absent. The researchers placed a total of 1,200 plasticine models of snakes at forty different woodland and desert locales in two wilderness areas, one in Arizona and another in North and South Carolina. About half the models in each area were placed inside coral snake territory, and half were placed outside it. When raccoons, coatis, foxes, coyotes, skunks, or bears bit the models, they left tooth marks in the plasticine.

Since there were far fewer attacks on king snake mimics within the ranges of real coral snakes, Pfennig believes that predators in these areas have developed an innate avoidance of snakes with bright-colored band patterns. How these mammals acquire their instinctive fear remains a question, as a single coral snake bite might well remove the "learner" from the gene pool. ("Frequency-Dependent Batesian Mimicry," *Nature* 410, 2001)—*Richard Milner*

EAU DE GENES Scientists and lovers alike have long known that fragrance plays a role in sexual communication. Now, research done by Manfred Milinski and Claus Wedekind while they were at the Universität Bern in Switzerland suggests some evolutionary explanations for odor preferences.

A set of genes involved in both scent recognition and conferring immunity to infection—known as the major histocompatibility complex (MHC)—is widespread in vertebrates. Both mice and humans, for example, have been shown to prefer the body odor of partners that possess MHC genotypes different from their own.

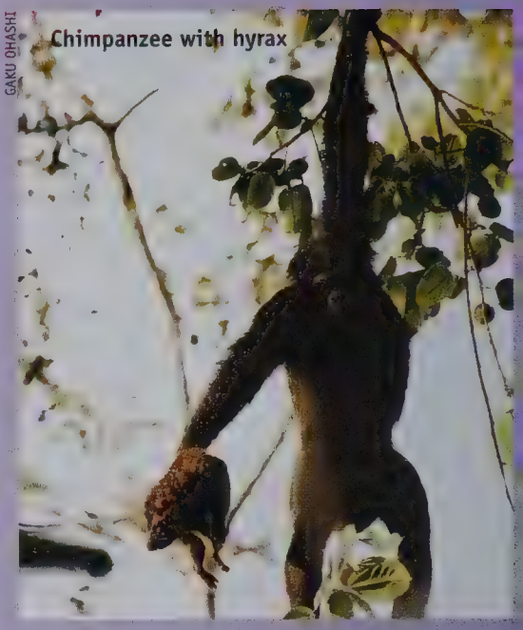
Milinski and Wedekind asked both women and men to assess various scents, indicating whether they would "like to smell like that" themselves or whether they would like to smell them on a partner. There was a positive correlation between the subjects' own MHC genes and the scents they chose for themselves—but a negative correlation for fragrances they selected for potential partners.

The researchers believe that people prefer fragrances that amplify—rather than mask—their natural body odor. By using perfumes that broadcast their genetic makeup to potential mates, and by selecting partners whose MHC genes are dissimilar to their own, individuals may reduce inbreeding as well as susceptibility to certain diseases. ("Evidence for MHC-Correlated Perfume Preferences in Humans," *Behavioral Ecology* 12, 2001)—*Kirsten L. Weir*

PLAY OR PREY If there's one fact emerging from all the field studies of chimpanzees, it is that chimp behavior and customs ("cultures") differ widely from place to place. Communities vary in their greeting behavior, use of tools, and food preferences. Because chimps are so closely related to us, primatologists carefully document any unusual behavior.

One recurrent question concerns the extent of ape carnivory. Observers have verified that chimp populations at Mahale Mountains Wildlife Research Centre in Tanzania kill ten different species of mammals and eat them, while other chimp groups at Bossou, in Guinea's southeastern corner, hunt much less frequently and prey only on tree pangolins. Still other communities are almost entirely vegetarian.

GAKU OHASHI



Satoshi Hirata, Gen Yamakoshi, and colleagues from Kyoto University in Japan have reported incidents in which chimps at Bossou captured and killed western tree hyraxes but did not eat them. At Bossou, they recently observed a mixed-sex group, including the alpha male, scream excitedly and then attack a hyrax that fell out of a tall tree.

In another incident, an adolescent male was seen moving through a tree swinging a live hyrax, then slamming it against the tree's branches. An eight-year-old female soon got hold of the motionless carcass, swung it in the air, and carried it. She finally settled into a tree nest, where she slept with the dead hyrax all night; the next morning, she groomed its fur, carried it around, and eventually let it drop to the ground.

Although chimps at Mahale do consume hyraxes, those at Bossou either let them go or kill them without eating them. Bossou chimps, which only rarely interact with hyraxes, apparently do not consider them prey. For further information, go to www.pri.kyoto-u.ac.jp/chimp/Bossou/Bossou.html. ("Capturing and Toying With Hyraxes *(Dendrohyrax dorsalis)* by Wild Chimpanzees *(Pan troglodytes)* at Bossou, Guinea," *American Journal of Primatology* 53, 2001)—*Richard Milner*

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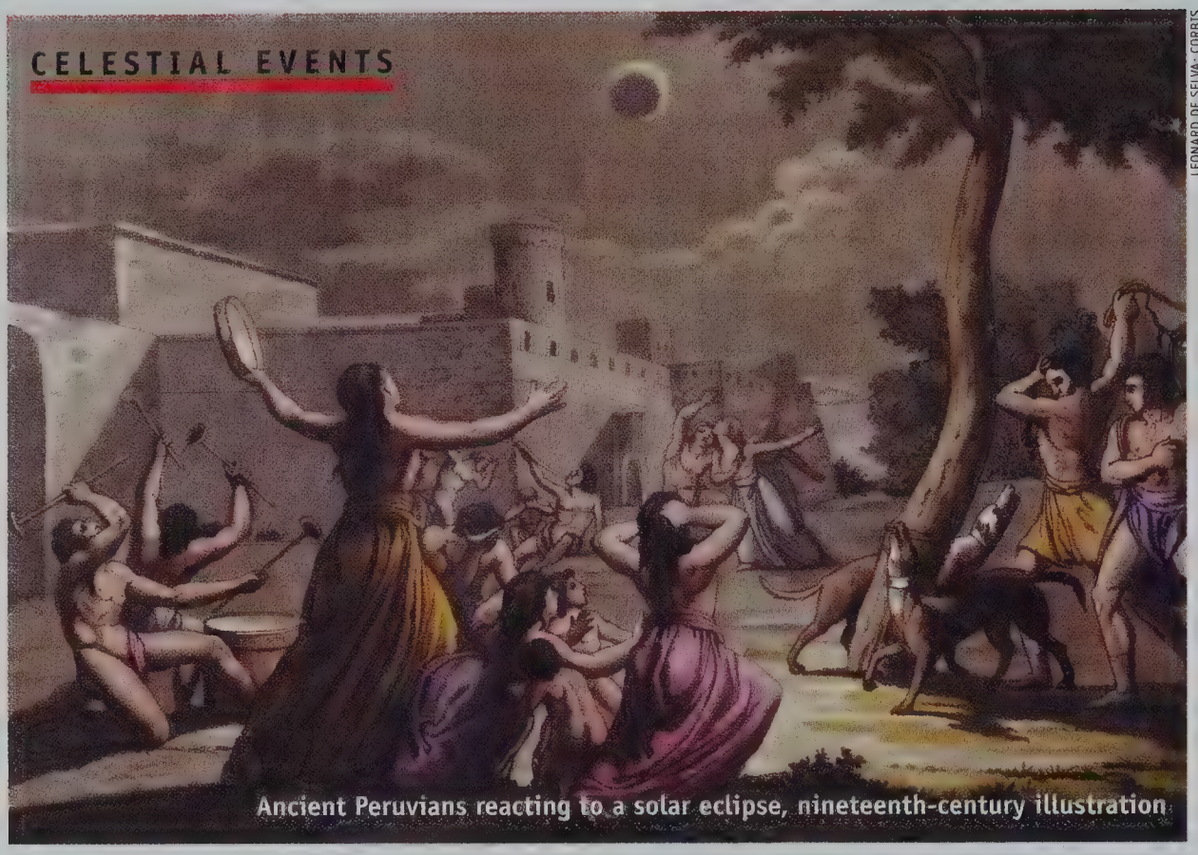


LEONARD DE SELVA; CORBIS

Ancient Peruvians reacting to a solar eclipse, nineteenth-century illustration

There Goes the Sun

Witnessing an eclipse today may not be the mystical experience it once was, but it's no less impressive.

By Richard Panek

"What you'll see," one of the cruise ship's official guides was saying, "you won't be able to describe to your family. People cry. People scream. People babble." An unofficial guide—the director of a planetarium back in the States and one of our fellow passengers—had a more frankly romantic interpretation of what we were about to experience: "I equate it with love."

Can any natural event (even love) possibly live up to such advance billing? The passengers aboard a special cruise on the Black Sea in August 1999 were about to find out—as will people taking similar sea cruises or land expeditions in Africa this month, when the moon once again totally eclipses the Sun. Such an event isn't particularly rare. Unlike spectacular comets, which tend to streak into view only once or twice a decade, total solar eclipses occur on average about once every other year. What makes them *seem* so rare, however, is their inaccessibility.

You can witness the Moon precisely superimposing itself upon the Sun only if you happen to be in the right place at the right time. The right place—the path of the Moon's umbral shadow—is 170 miles across at its widest, and the right time—totality itself—can be seven minutes, thirty-one seconds at the longest and usually lasts several minutes less. A total solar eclipse will be visible at a given place on Earth only once about every 375 years on average, so if you want to see any of the three dozen or so such events that are going to occur during your lifetime, chances are *you* are going to have to go to *it*.

Which helps explain why eclipse cruises and land expeditions have become popular—and the best such tours not only get you there but also provide lectures and briefings on what to expect when totality arrives. That's not to say that the eclipse cruise I took in 1999 didn't have a casino or an onboard band featuring "The Girl From Ipanema" in its repertoire. Nor was every passenger "chasing totality," as eclipse veterans like to say: on the morning of the main event, fifteen passengers passed up the final and most extensive preparatory briefing in favor of a napkin-folding tutorial. Still, those of us who did go to the middle of the Black Sea for a good look at what some tour organizers were billing as "the last total solar eclipse of the millennium" found ourselves trying to get the most out of our two minutes and twenty-one seconds.

Among the phenomena any observer of a total solar eclipse can anticipate are

Weather. After the edge of the Moon meets the edge of the Sun, the temperature may begin to drop noticeably. Aboard our ship, idling in the August heat of the Black Sea, it fell 21° F altogether, to 83° at totality.

Shadow. Just before the beginning of totality, the shadow of the Moon will visibly race across the landscape—in our case, the calm surface of the sea—from the west.

Baily's beads. When the last rays of the Sun poke through the valleys

along the perimeter of the Moon's disk, they create an effect that nineteenth-century British amateur astronomer Francis Baily described as "a string of bright beads."

Diamond-ring effect. The final Baily's bead appears together with the visible band formed by the solar corona.

Wildlife. Birds and beasts will be responding, perhaps starting to bed down for the "night" as the sunlight dims. But the response of human beings will be no less notable. As my fellow cruise passenger Robert J. Bonadurer, director of the Minneapolis Planetarium, said, "You can tell yourself that you don't believe the world is going to come to an end—but you *do*. And then you understand people shooting arrows at the Moon."

To be sure, a total eclipse of the Sun is not without its scientific applications, whether it's Arthur Eddington using photographic images of the 1919 eclipse to help validate Einstein's general theory of relativity or today's astronomers monitoring the event to view the corona, the highly ionized gases surrounding the Sun. But the psychological impact of seeing the perfect fit between Moon and Sun—the only such coincidence visible from the surface of a planet in our solar system—is what casual observers remember.

They'll be watching this month (see "The Sky in June," below, for details). And if you need any evidence that the impact of a solar eclipse is more psychological than scientific, consider what happened on our cruise immediately after totality. As the sight of the Moon creeping across the Sun—the spectacle that minutes earlier had awed everyone—continued to play itself out, only in reverse, hardly anyone paid attention. The band resumed playing; the totality chasers drank champagne and danced. Off to one side, Anthony F. Aveni, professor of astronomy and anthropology at Colgate University and one of the official onboard experts, noticed that our ship as well as several others in our immediate vicinity were already barreling back across the Black Sea. "We're all heading for the Bosporus," Aveni laughed. "We've abandoned the midline. What a bunch of eclipse hypocrites we are!"

Richard Panek is the author of Seeing and Believing: How the Telescope Opened Our Eyes and Minds to the Heavens *(Penguin, 1999).*

THE SKY IN JUNE

By Joe Rao

Mercury swings between Earth and the Sun this month, reaching inferior conjunction on June 16. This is not the best month for Mercury hunters, as their target will be cloaked by the blinding solar glare.

Venus, by far the brightest of the planets, rises every morning just before dawn. At twilight it is unmistakable as it ascends in the east. The planet attains its greatest elongation as early as June 8. On the 17th the Moon appears well below and to the right of Venus; on the 18th the Moon is a similar distance below and to its left.

Mars dominates the night skies this month, reaching opposition on June 13, when it shines at an eye-popping magnitude of -2.4. On June 21 it is only 41.8 million miles away, its closest approach to Earth since October 19, 1988. Mars retrogrades among the stars of Ophiuchus all month. At 40° north latitude, it rises about an hour after sunset at the beginning of June and appears well to the right of an almost full Moon, rising together with it on the 6th. By the 13th the fiery planet rises as the Sun sets, and by month's end, it is already well above the east-southeastern horizon at dusk.

Jupiter's solar conjunction occurs on the 14th, and the planet is invisible for most of June. At month's end, it might be glimpsed just above the east-northeastern horizon about forty-five minutes before sunrise. This marks the beginning of a yearlong apparition, when the giant planet will blaze within the stars of Gemini.

Saturn will be too close to the Sun during the first two weeks of June to be seen, but after midmonth, it begins to emerge low in the east-northeastern sky about two hours before sunrise. On the morning of the 19th the yellowish planet will be below and to the left of the Moon's crescent.

The Moon is full on June 5 at 9:39 P.M. Last quarter comes on June 13 at 11:28 P.M. The new Moon falls on the 21st at 7:58 A.M., and first quarter is on the 27th at 11:19 P.M.

A total solar eclipse, the first of the century, will get under way at 6:37 A.M. on June 21 and can be viewed along a narrow swath starting in the South Atlantic, crossing Angola, Zambia, Zimbabwe, and Madagascar, and ending in the Indian Ocean. The Moon's umbral shadow cone will first touch Earth far off the coast of Uruguay. The open waters of the South Atlantic will experience the longest totality: four minutes and fifty-seven seconds.

Summer solstice occurs on June 21 at 3:38 A.M. in the Northern Hemisphere.

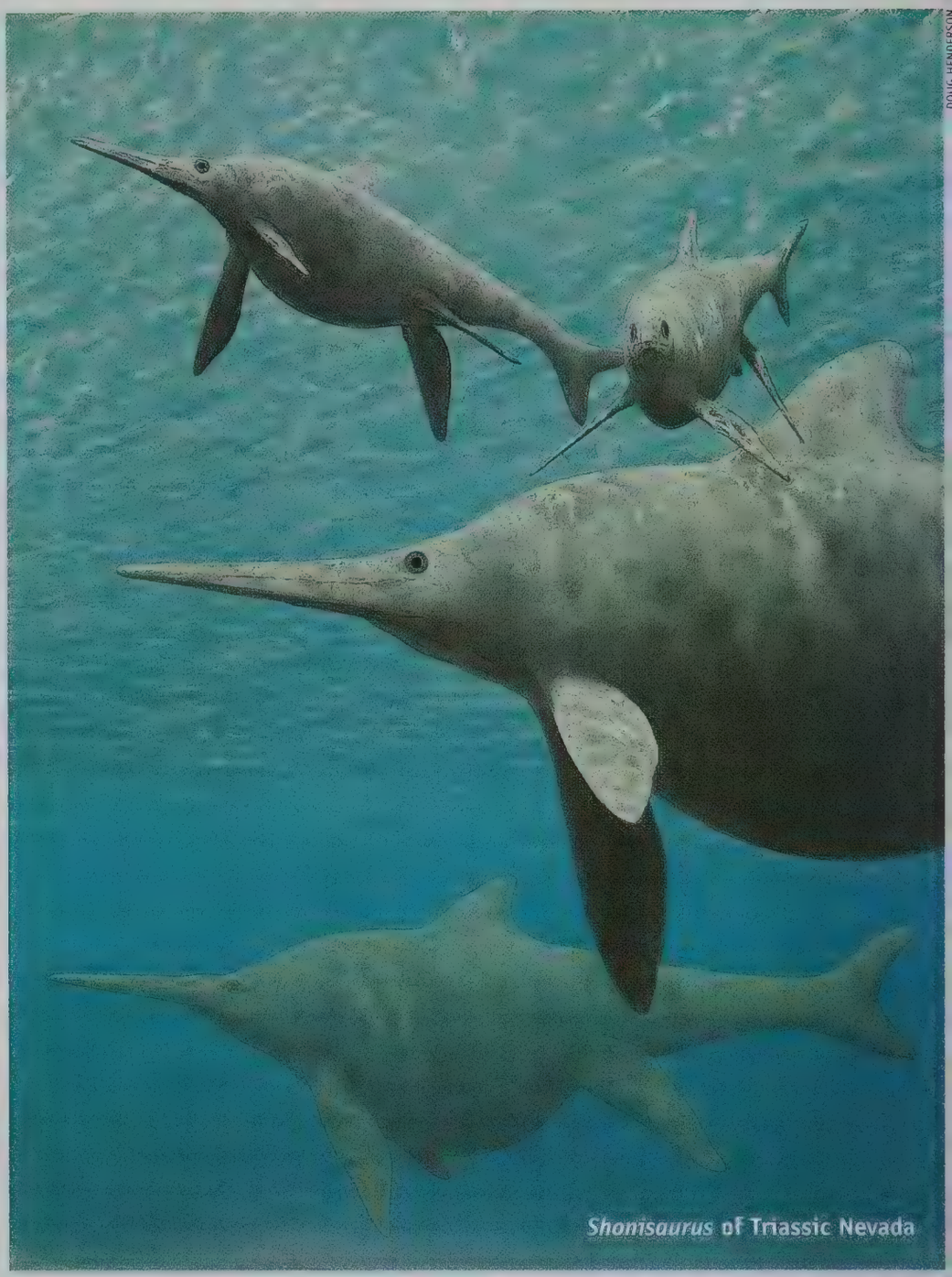
Unless otherwise noted, all times are given in Eastern Daylight Time.

THIS LAND

How the West Was Swum

At Nevada's Berlin-Ichthyosaur State Park, fossils of giant marine predators point to the region's watery past.

By Richard L. Orndorff, Robert W. Wieder, and Harry F. Filkorn



Shonisaurus of Triassic Nevada

DOUG HENDERSON

Berlin-Ichthyosaur State Park sits on the western flank of Nevada's Shoshone Mountains, about 7,000 feet above sea level. Today a seemingly endless expanse of sagebrush covers the relatively featureless landscape of the valleys, while the rocky slopes of the mountains support scattered sagebrush and stands of juniper and piñon trees. This sparsely populated part of Nevada has changed little since the first settlers arrived more than one hundred years ago. But it has changed much since the largest marine predators of the Triassic Period lived here, more than 200 million years ago.

Extinct reptiles that plied ancient oceans, ichthyosaurs had highly streamlined bodies resembling those of some of today's fastest fish, such as swordfish, marlin, and tuna. Despite their fishlike exteriors, ichthyosaurs had to surface to breathe air and they gave birth to live young. Their elongate mouth and strong jaws held rows of pointed conical teeth, similar in shape to those of modern toothed whales. A circular set of overlapping bony plates internally reinforced the disproportionately large eyes of some ichthyosaurs and compensated for changes in water pressure when the animals dived or surfaced. This feature enabled them to consistently maintain their highly developed sense of vision at all swimming depths.

Fossil ichthyosaurs are common in the sedimentary rocks that make up Nevada's Luning Formation. About 230 million years ago, when these sediments were deposited, North America was part of the northern supercontinent known as Pangaea, and the Panthalassa Ocean covered much of what is now the western United States. Outcrops, or protruding layers of rock, of the Luning Formation are scattered throughout the mountain ranges of central Nevada, and paleontologists have found ichthyosaur remains in the West Humboldt Range and the New Pass Range, as well as in

Adapted from *Geology Underfoot in Central Nevada*, by R. L. Orndorff, R. W. Wieder, and H. F. Filkorn. © 2001 by the authors. Reprinted by permission of Mountain Press Publishing Company, Missoula, Montana.

Union Canyon in the Shoshone Mountains, the site of Berlin-Ichthyosaur State Park.

The first ichthyosaur bones discovered in Union Canyon were excavated by gold prospectors from the mining town of Berlin (now a well-preserved ghost town and part of the state park). While the miners saw the bones as novelties and sometimes used them to decorate their cabins, the fossils did not become known to the scientific community and recognized as the remains of ancient reptiles until 1928. The first field expedition to Union Canyon was launched by Berkeley paleontologist Charles L. Camp and his colleague Samuel P. Welles in 1954. Today a stroll through Union Canyon takes visitors by Camp's cabin, where he and other scientists worked diligently for years to reconstruct the ichthyosaurs' skeletons and solve the puzzle of their presence here. Union Canyon has yielded at least thirty-seven mostly complete ichthyosaur skeletons. In 1966 an A-frame shelter was built over the main quarry to protect some of the exposed fossils and allow visitors to see them. The skeletons of nine individuals, their bones still embedded in rock, are on view. While Camp considered the Union Canyon fossils to be of three different species of ichthyosaurs, all the specimens are now thought to be the remains of a single species, *Shonisaurus popularis,* named for the surrounding mountain range.

Thanks to the abundance of *Shonisaurus* specimens collected in the region, scientists know more about the skeleton of this species than about any other Late Triassic ichthyosaur. Fifty or more feet long and weighing an estimated forty tons, *Shonisaurus* was one of the largest creatures of its time—about the size of a modern sperm whale and twice the size of a killer whale. Larger individuals had six-foot-long front fins, twenty-five-foot-long tails, and ten-foot-long skulls with elongate jaws, filled with conical teeth. In contrast, the well-preserved ichthyosaurs found in shale quarries in Holzmaden, Germany, which date from the Jurassic Period, were only the size of today's dolphins.

While fossil bones tell us about the body plans of extinct creatures, the composition of the surrounding rock can give clues to the environments they inhabited and help answer such questions as how so many large ocean-going predators ended up in the Shoshone Mountains. At the time the Union Canyon ichthyosaurs lived, the region was a tropical sea, situated along the west coast of what is now North America. The bedrock in the area indicates that the ichthyosaur bones were deposited in a deep ocean shelf environment. One of the most convincing pieces of evidence is the fine-grained sedimentary rock that encloses the fossils. As rivers carrying sediment spill into the ocean, freshwater mixes with standing marine water, and the momentum of the flow decreases; as a result, coarse sediment drops to the bottom near the shore. Fine sediment remains in suspension much longer and travels far out to sea, where it settles slowly to the bottom. The sediment layers in the Union Canyon rocks suggest they accumulated in the deeper areas of the continental shelf.

LARRY ANGIER

Ichthyosaur bas-relief and trail of vertebrae

Other fossils found with the ichthyosaur remains also support the idea that this was a deepwater environment. Most of these are from swimming organisms, such as ammonoids and nautiloid mollusks that lived just above the deep seafloor. The general scarcity of fossils of scavenging marine animals also fits well with this interpretation, because scavengers tend to be less numerous in deep marine waters. In contrast, other rock layers of the Luning Formation contain an abundant and diverse assemblage of mollusks, corals, echinoderms, and sponges that typically lived in shallower waters.

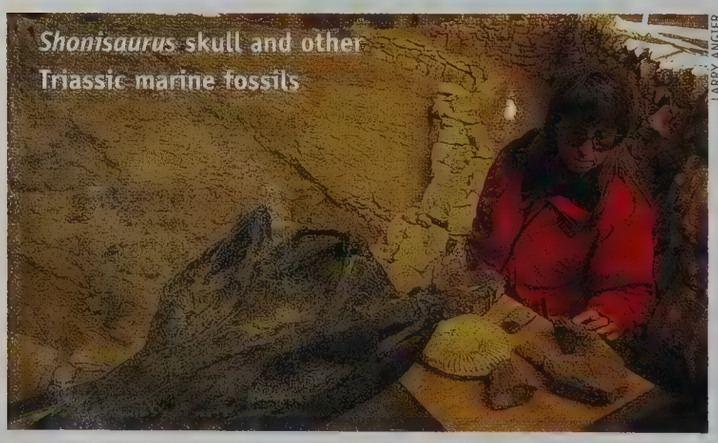
Most of the *Shonisaurus* skeletons are articulated; that is, the bones are still in the correct anatomical position relative to one another. Strong ocean currents would have moved at least some of the carcasses during their decomposition, and the bones would have been scattered during their transport. Thus currents must have been fairly weak, as they typically are in deeper water. The corroded and pitted surfaces of some of the bones, and the presence of brachiopod shells on them, suggest that the bones lay exposed on the seafloor for a time, but the relative completeness of the skeletons indicates that they were buried on the seafloor soon after the flesh had decomposed.

One major unresolved problem concerns the explanation for exactly how so many ichthyosaur skeletons came to be preserved so close to one another. Two plausible explanations exist. The ichthyosaurs may have died singly over an extended period; according to this scenario, their carcasses sank to the bottom, and weak currents naturally concentrated them into a depression, or submarine valley, on the seafloor. Alternatively, this deposit of multiple ichthyosaur skeletons could represent a massive die-off.

Based mainly upon studies of modern marine vertebrates, various theories, of varying plausibility, have been proposed to account for the sudden-mass-mortality scenario. Changes in the physical or chemical conditions of the seawater have been proposed as a cause of death, but any change drastic enough to kill ichthyosaurs would also have killed other marine organisms. However, no other fossil evidence exists along with the ichthyosaur bones to indicate any such additional die-off. Volcanic eruptions could have killed many ichthyosaurs, but then we should see some evidence, such as a volcanic ash layer, preserved in the sediments. None is present in the rock record. Similarly, the stratigraphic record lacks evidence of a severe storm, for example, a coarser-grained layer of sediment. The notion that some ichthyosaurian behavior—such as spawning, stranding, or coastal foraging—brought these *Shonisaurus* together is improbable. As dramatically evidenced in fossils from other sites, ichthyosaurs bore live young, so they did not spawn en masse as do many fish. And while mass mortality by stranding was previously supported as a cause for the concentrations of skeletons here, researchers now consider that scenario unlikely, given the evidence for an ocean shelf, rather than a coastal, setting.

One intriguing possibility is that the ichthyosaurs ate fish or shellfish tainted with a neurotoxin that paralyzed them. (Paralytic shellfish poisoning in humans also results from a neurotoxin.) Such a poison may have originated at the base of the marine food chain, in oceanic plankton, and then become concentrated in the tissues of the animals that ate the plankton. The *Shonisaurus,* top predators and consumers in the food chain, may have eaten these plankton-feeding organisms and perished. This type of poisoning mechanism has triggered some of the mass kills of modern whales along the coast of New England.

Over the years, scientists have revised and refined their views of how *Shonisaurus popularis* lived as an active predator and how it came to rest on the seafloor. Each new generation of paleontologists builds on the work of those who came before, providing some answers but invariably providing many more questions. A visit to Berlin-Ichthyosaur State Park is an opportunity to ponder the giant predators and their ancient environment. As you investigate the *Shonisaurus* fossils, you might want to consider some of these questions. And ask some of your own.



Park Ranging

The state of Nevada, which has adopted *Shonisaurus popularis* as its state fossil, first officially recognized the importance of Union Canyon in 1955, when it designated the site Ichthyosaur Paleontological State Monument. In 1970 the boundaries were expanded to include the mining ghost town of Berlin, and the site was renamed Berlin-Ichthyosaur State Park.

Located about twenty-three miles east of the town of Gabbs, the park offers guided tours of the Fossil Shelter, the ghost town of Berlin, and the Diana Mine rock tunnel used by the Berlin prospectors. Camping is available, and an extensive system of hiking trails can help visitors enjoy the juniper and piñon woodland, examine the local bedrock, or catch sight of wildlife. Eagles, rattlesnakes, deer, pronghorn antelope, foxes, coyotes, and mountain lions roam the area.

For visitor information on seasonal access, tour schedules, and rules and regulations, contact:
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Richard L. Orndorff is assistant professor of geology at the University of Nevada, Las Vegas; Robert W. Wieder is a biologist at the California Department of Agriculture; and Harry F. Filkorn is a paleontologist at Kent State University in Ohio.

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BIOMECHANICS

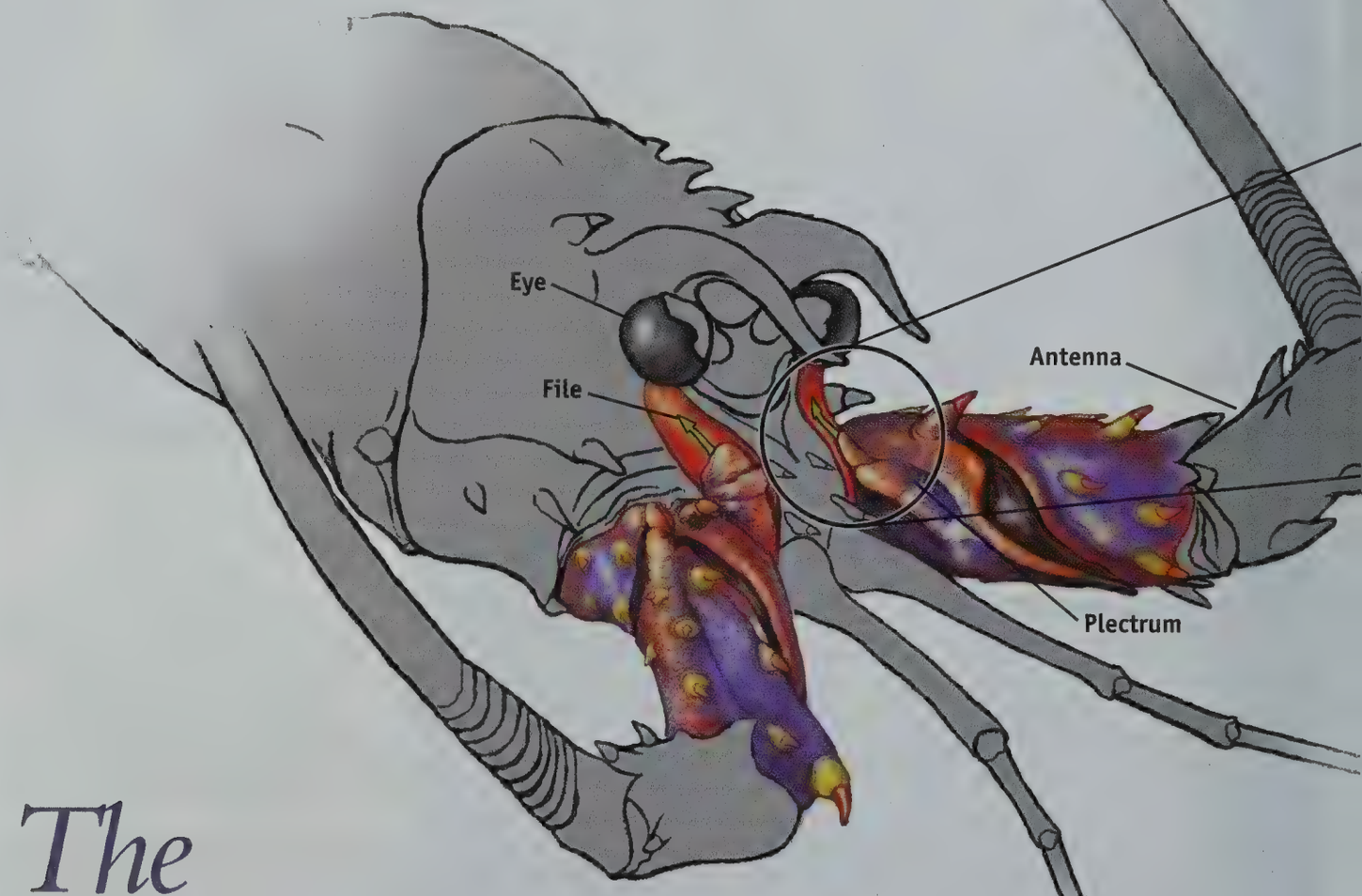
The Lobster's Violin

It's enough to give a predator pause.

Story by Adam Summers ~ Illustration by Sally J. Bensusen

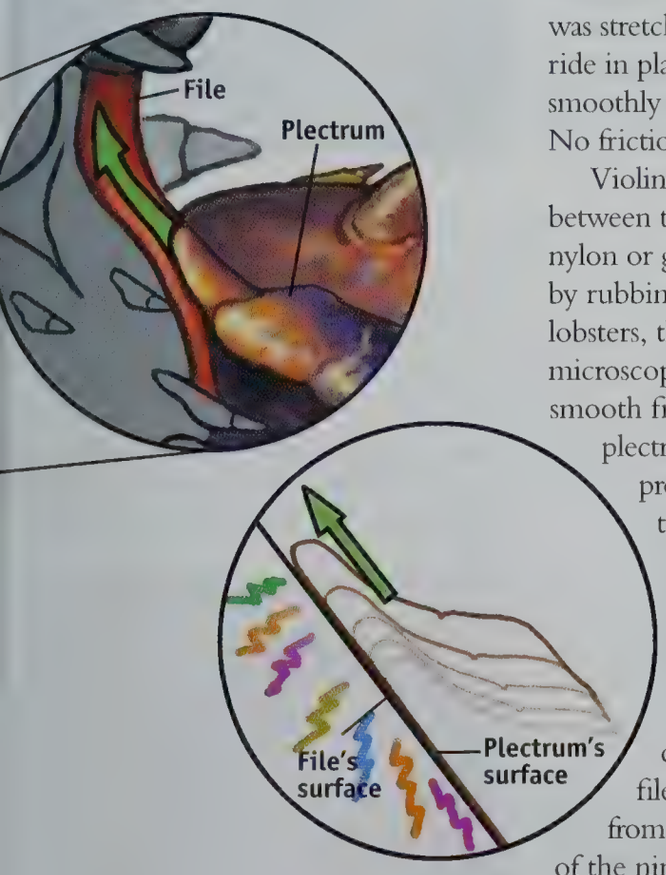
Some lobsters and many eight-year-old violinists have a knack for making unpleasant noises; amazingly, crustaceans and humans use much the same mechanism to produce these awful sounds. The lobsters in question are not Maine's clawed variety but members of a family known as the Palinuridae, or spiny lobsters. These clawless marine invertebrates, found worldwide, often appear on menus as rock lobster or New Zealand lobster tail. Instead of a showy pair of claws, two long antennae are their most striking feature. The base of each antenna (where it joins the head) is thick and spiny—the reason for the lobster's common name.

Many invertebrates, such as crickets and cicadas, make noise by "plucking" a series of spikes or ridges (usually on their legs or wings)—much like a person drawing a thumbnail across a comb or a pick across guitar strings. But Sheila Patek, of Duke University, has discovered that spiny lobsters produce sound in a very different way: by drawing a bow across a vibrating surface. In this case the "bow," called the plectrum, is a flattened protuberance (actually a series of soft ridges) emerging from the basal segment of each antenna. (Earlier researchers thought the lobster's plectrum functioned like a pick; hence the confusing mix of terms.) The analogue of the violin string is the file—an oblong lump, or pad, one on either side of the lobster's head. By waggling an antenna, the lobster draws the plectrum across the file;



the result is a surprisingly loud, rasping buzz. (One striking difference between lobster and violinist, of course, is that no amount of practice will turn this buzz into music.)

This type of mechanism is known as stick-and-slip motion. Imagine a box of rocks sitting on a conveyor belt, but instead of being able to move freely along the belt, the box is secured to a wall by a spring. As the belt moves, the box rides with it, stretching the spring. At some point, the tension of the spring becomes greater than the frictional force (the amount of resistance to movement that occurs between two moving objects in physical contact) between box and belt, and the box skitters along the belt toward the wall. This backward movement shortens (and thus reduces the tension of) the spring, permitting the box once again to ride the belt. Each time the box skips back across the belt, it makes an audible rumble; when the box rides smoothly, there is silence. The key to stick-and-slip sound production is friction. If the conveyor belt was greased, the box would move forward until the spring was stretched taut. Then the box would ride in place, with the belt sliding smoothly and soundlessly underneath it. No friction, no sound.



To generate its loud, raspy buzz, the spiny lobster waggles one or both of its antennae, causing a flattened projection (the plectrum) on each antenna's spiky base to skid across an oblong lump (the file) located on either side of the animal's head, near the eye. Microscopic shingles on the file create friction, which is essential to sound production.

Violinists enhance the friction between the horsehair bow and the nylon or gut strings of their instrument by rubbing rosin on the bow. For lobsters, the friction comes from microscopic shingles on the otherwise smooth files. Each time the lobster's plectrum skids on the file, it produces a pulse of sound. As it travels the length of the file, the plectrum generates between two and twenty-four of these pulses, creating the characteristic raspy squeak. The duration of the sounds depends on the length of the file, which varies considerably from genus to genus. In fact, seven of the nine genera of spiny lobsters can be identified by the shape of their files and plectra. (The other two do not have files and thus make no noise at all.)

Patek believes that lobsters make these raucous sounds to deter predators. Think how you would react if a hot dog let out a loud squeak when you picked it up. However, the sound may do more than just startle potential predators. Spiny lobsters can do considerable damage with their stout antennal bases, which may be several inches long. In captivity they wield these spiky clubs aggressively and even catch the occasional fish dinner by slamming their antennae together. In the wild, lobsters may use sound to warn a predator that it is about to get clunked. Or the noise may simply inform a shady character that the element of surprise has been lost—the lobster version of "I've got my eye on you."

In any case, there is a very important biological reason a lobster would prefer a violin to a guitar. Lobsters, like all animals with exoskeletons, periodically shed their armor as they grow. As anyone who has appreciated soft-shell crabs can attest, naked crustaceans are both tasty and easy to eat. If a spiny lobster had to produce sound the way guitarists so often do—by plucking a hard plectrum across a series of hard ridges—the animal would be obliged to fall silent just when it would benefit most from an antipredator noisemaker: during the vulnerable few days it takes for the carapace to harden following a molt. The great advantage of the stick-and-slip approach is that a soft structure rubbing against another soft structure works just as well right after a molt as it did beforehand.

Many animals produce sounds to communicate with their own species—to issue warnings or invitations or to affirm their presence. Spiny lobsters appear to have developed this communication system solely to talk to other species. Their predators can certainly hear sounds in the range produced by the plectrum and file, but as far as we know, the lobsters themselves are completely deaf to their own playing.

Adam Summers is an assistant professor at the University of California, Irvine.

ESSAY

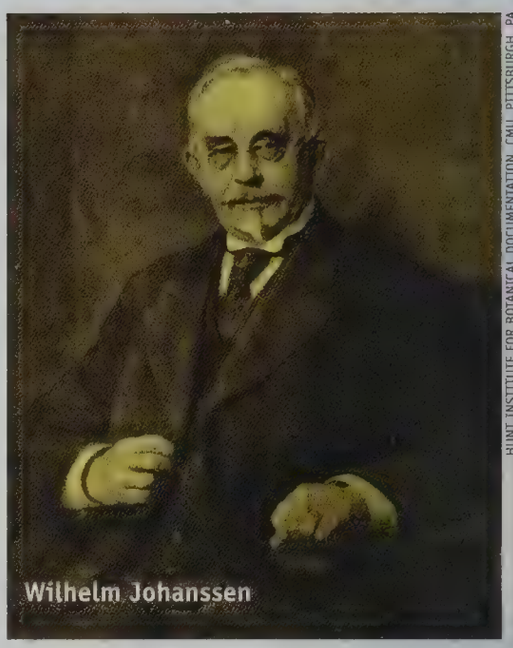
Are Genes Real?

Our understanding of heredity has been propelled by the oscillations of a conceptual pendulum, arcing between the gene as a real entity and the gene as an abstraction.

By Nathaniel C. Comfort

At the entrance to the California Academy of Sciences in San Francisco, a 235-pound brass pendulum bob swings on a thirty-foot cable fixed to the cathedral ceiling. It is known as a Foucault's pendulum, after Jean-Bernard-Léon Foucault, a French physicist of the nineteenth century. Each arc of the pendulum cuts a diameter across a ring of metal pegs set on the floor. As the earth rotates, each peg in turn moves into the path of the giant bob and is knocked over. Although the pendulum swings in a straight line, it never returns to the same spot twice in succession.

Science often behaves more like a Foucault's pendulum than like the forward march of progress depicted in textbooks and newspapers. An idea may oscillate between two extremes, yet as the world of science shifts beneath its path, each swing results in a different incarnation of the idea. One such idea is whether or not genes are real. If the accumulation of scientific knowledge were linear, the idea of the gene ought to have started out vague and become progressively more sharply delineated with time. In fact, over the past 150 years, our understanding of heredity has been propelled by the oscillations of a conceptual pendulum,


Wilhelm Johanssen

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Gregor Mendel

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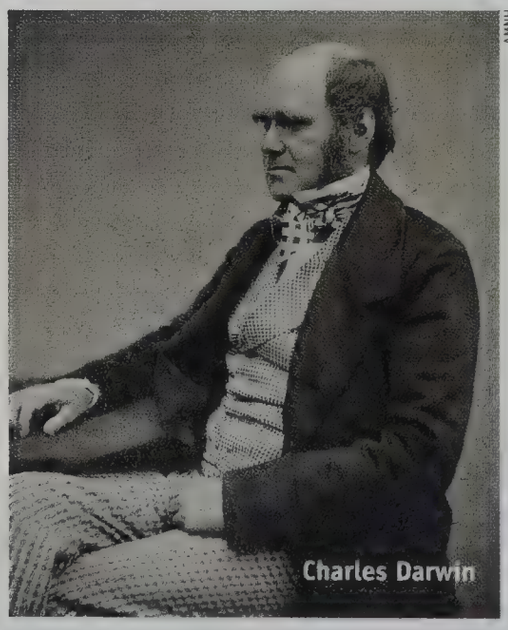
Charles Darwin

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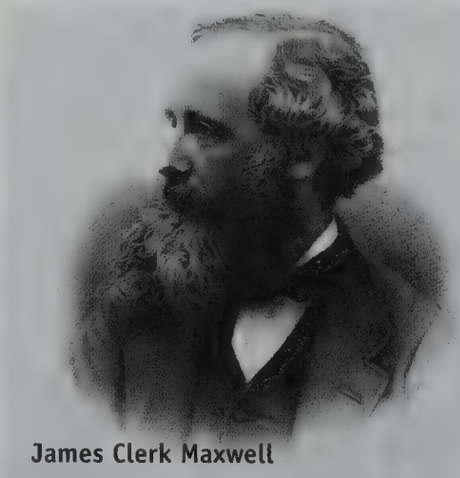
James Clerk Maxwell

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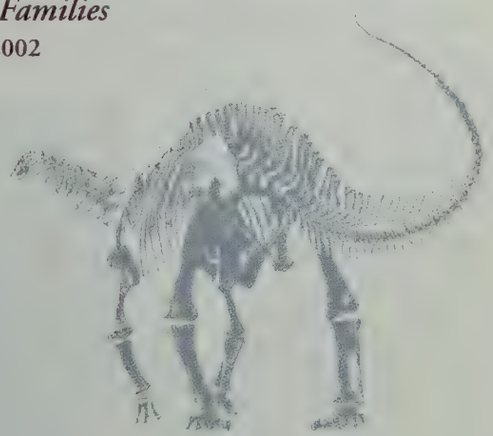

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arcing between a real gene and an abstract one.

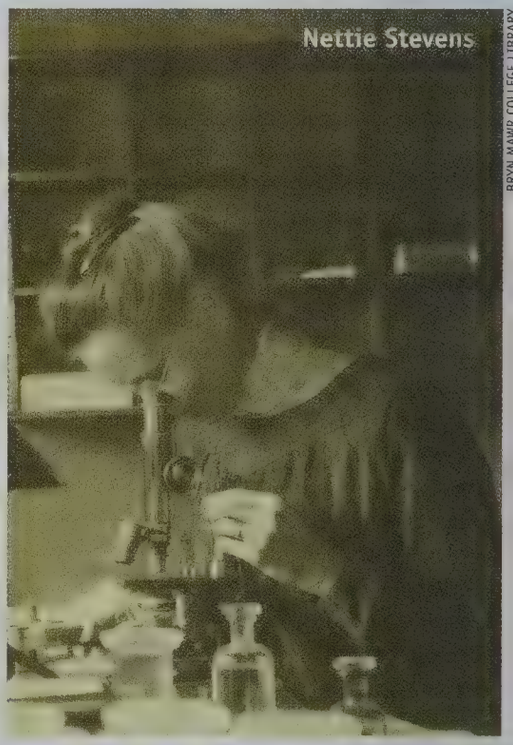
The word "gene" was coined in 1909 by Wilhelm Johanssen, a well-known Danish botanist of the late nineteenth and early twentieth centuries. During the preceding four decades, Gregor Mendel, Charles Darwin, and many other scientists had proposed theories of how hereditary traits were passed down through the generations. Mendel, the canonical father of genetics, modeled the inheritance patterns of seven carefully chosen "differentiating characters" *(differierende Merkmale)*—for example, stem length, pod shape, color and texture of the seeds—in garden peas. At the end of a paper published in 1866, Mendel hinted that the *Merkmale* might lie in the cell nucleus, but he did not distinguish between the traits seen in the plant and the hereditary elements that produced them. For Mendel these elements were abstractions, useful in understanding the patterns of inheritance.

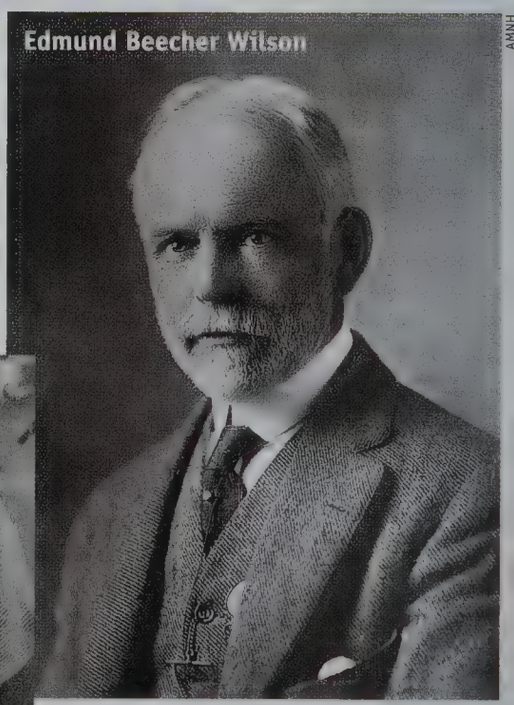
Gregor Mendel did not distinguish between the traits seen in a plant—such as seed color and texture, pod shape, and stem length—and the hereditary elements that produced them.

The hereditary elements proposed by Darwin were more physical—and therein lay their downfall. In 1868, unaware of Mendel, Darwin put forth his hypothesis of pangenesis, in which trait-bearing particles that he called gemmules budded off from the body's tissues and collected in the reproductive cells, where they waited to be passed on to the next generation. Pangenesis won few adherents. The great physicist James Clerk Maxwell even digressed from his 1875 *Encyclopædia Britannica* essay "The Atom" to take a swipe at it. "Some of the exponents of this theory of heredity have attempted to elude the difficulty of placing a whole world of wonders within a body so small and so devoid of visible structure as a germ," he wrote, referring to Darwin's gemmules. To Maxwell—an expert on particles—no simple particle could conceivably explain the wonders of heredity and embryology. "To explain differences of function and development of a germ without assuming differences of structure," he continued, "is to admit that the properties of a germ are not those of a purely material system." Advocating hereditary particles seemed tantamount to mysticism.

Nevertheless, in the late 1800s it was Darwin's theory, not Mendel's, that had the most influence. Mendel died in 1884, and his paper was largely ignored until the turn of the century; it was cited just a handful of times and never as a landmark in the study of heredity. Though Darwin's theory of pangenesis was soundly rejected, it continued to echo throughout the rest of the century. The major theories of heredity put forward in the 1880s and 1890s also assumed the existence of real, physical particles, with such exotic-sounding names as ids, biophors, and pangenes.

When Mendel's principles, with their mathematical treatment of heredity, were rediscovered in 1900, however, the pendulum swung back toward abstract genes. One of Mendelism's staunchest





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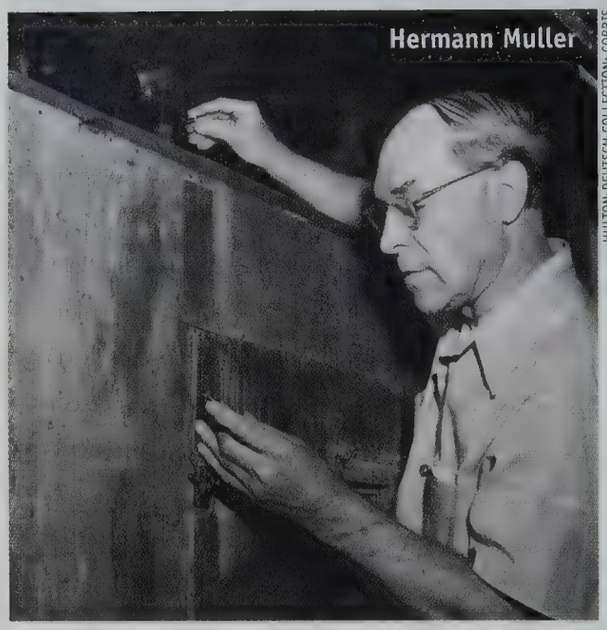

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partisans was William Bateson, an English biologist who saw in it a weapon for his attacks on the Darwinian idea of continuous variation in nature. Making the units of heredity abstract helped Bateson contradict this view, which was predicated on material particles. Bateson referred to the Mendelian elements as unit characters—a deliberately abstract term—and he passionately denied their material existence.

A young American embryologist named Thomas Hunt Morgan followed this trend. In 1903 Walter Sutton, an American cytologist, offered a cellular explanation of Mendel's principles, suggesting that Mendelian elements lay on the chromosomes. Two years later, geneticist Nettie Stevens (a former student of Morgan's) showed that sex was associated with the mysterious "accessory," or X, chromosome. Morgan, however, was skeptical. Given the limited evidence then available, too many assumptions were required and not enough biology was explained. Advocates of the chromosome theory seemed to him enthusiasts, bandwagon jumpers. In 1905 he wrote that his colleagues at Columbia University, especially the distinguished cytologist Edmund Beecher Wilson, were "wild over chromosomes," making Morgan feel he lived "in an atmosphere saturated with chromosomic acid."

In 1910 Morgan abruptly tipped the other way. Among the thousands of fruit flies he was breeding in his laboratory, he found a single male with white eyes, rather than the usual red. Breeding experiments revealed that eye color was inherited together with a "factor" that determined sex. Stevens's results could no longer be ignored. Sex and eye color were linked by association with the X chromosome.

Morgan and his graduate students at Columbia made genes real again. During the following years, they developed the first gene maps, assigning genes for various traits to different chromosomes and measuring the distance between genes in terms of the likelihood that two traits would be inherited together, much as blond hair often goes with blue eyes. To these early fruit-fly geneticists, a gene was roughly synonymous with a locus, a physical point on a chromosome. In 1922 Hermann Muller, one of Morgan's former students, went further, describing genes as "ultra-microscopic particles." Muller dreamed of one day being "able to grind genes in a mortar and cook them in a beaker."

> To Thomas Hunt Morgan and the other early fruit-fly geneticists who put together the first gene maps, a gene was roughly synonymous with a physical point on a chromosome.

Practitioners of this "classical" school of genetics mostly ignored the question of what genes were made of. The question of most interest to them was what genes *did*. Working at Stanford University with the bread mold

Neurospora, George Beadle, a geneticist, and Edward Tatum, a chemist by training, provided an elegant answer in 1941. They identified genetic mutations that disabled specific steps in the synthesis of a complex molecule. Knowing from biochemistry that each step was catalyzed by a particular enzyme, they concluded that each mutation knocked out one enzyme. In classical genetics, genes had been defined as things that, when mutated, changed a trait: one mutation, one gene. Beadle and Tatum refined the definition by showing that a gene was a thing on a chromosome that specified an enzyme: one gene, one enzyme.

As Beadle and Tatum's work became accepted, more and more scientists thought of genes as real entities. This did not happen overnight, however, and there were critics. One of the most eloquent—and most aggravating to advocates of real genes—was Richard Goldschmidt, a brilliant, cantankerous German who in 1936 fled Nazi Germany and took up a post at the University of California, Berkeley. "There are no genes," Goldschmidt wrote in 1937, and "no gene mutations." In 1951 he continued his attack on the gene by suggesting this analogy: "If the A-string on a violin is stopped an inch from the end, the tone C is produced. Something has been done to a locus in the string, it has been changed in regard to its function. But nobody would conclude that there is a C-body at that point."

Within two years, Goldschmidt's provocative criticism seemed absurd. In April and May of 1953, James Watson and Francis Crick published their two papers describing the double-helical structure of DNA. The genius of their model was that the structure of the molecule and the structure of the gene were one and the same. With the double helix finally came insight not just into how genes worked but also into what they were made of. A gene was merely a particular sequence of nu-

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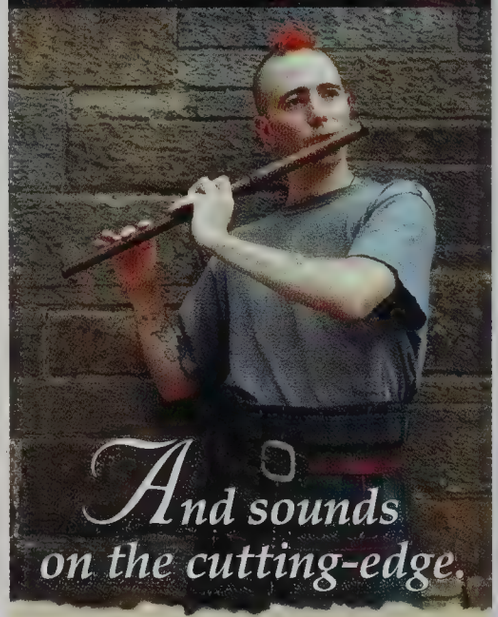

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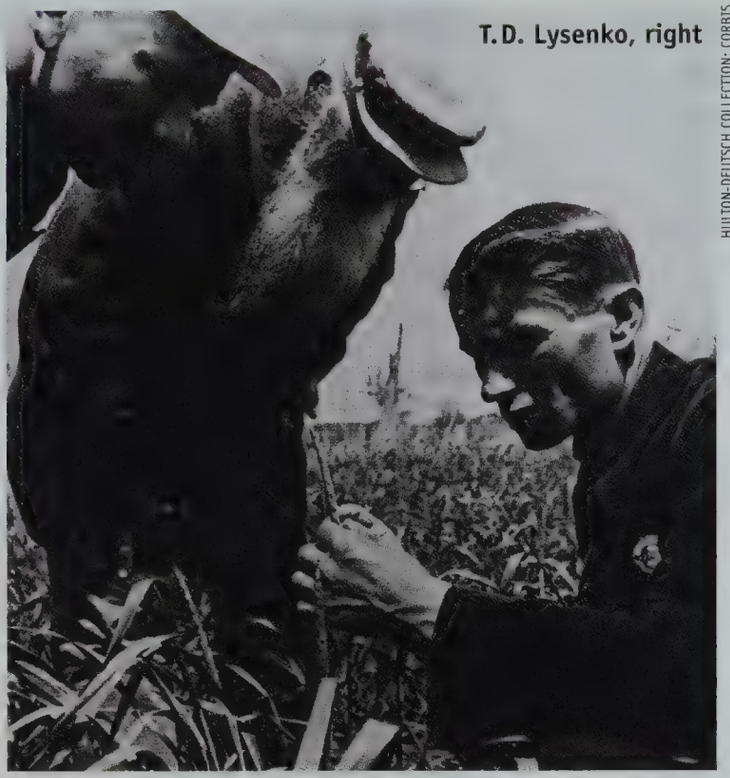

T.D. Lysenko, right

HULTON-DEUTSCH COLLECTION; CORBIS

James Watson, left, and Francis Crick

BETTMANN ARCHIVE; CORBIS

DNA! Everybody speaks about it, but nobody has seen it!" Englehardt explained that in fact plenty of people had seen it, and he sent his secretary to fetch some. When she returned with a vial of powdered DNA, Lysenko retorted, "Ha! You are speaking nonsense! DNA is an acid. Acid is a liquid. And *that's* a powder. That can't be DNA!"

Yet just when it became clear that only cranks could deny the reality of genes, the scientific ground began to shift again. In 1957 Seymour Benzer, a physicist turned viral geneticist at Purdue University, proposed that more than one type of gene existed, and he suggested the term "cistron" for a segment of DNA that encodes a protein. This was, in essence, the gene of Beadle and Tatum expressed in the language of cleotide subunits of a DNA strand—not a pearl on a string but the string itself.

For most geneticists, the discovery of the double helix instantly and unequivocally settled the debate in favor of real genes; from that point on, skeptics provided little more than comic relief. Horace Freeland Judson reports an anecdote told by Russian biochemist Vladimir Englehardt about his meeting in 1961 with Trofim Denisovich Lysenko, the infamous Soviet agronomist who rejected Mendelism and Darwinism as inconsistent with Stalinist ideology. Lysenko scoffed, "All this DNA, Watson and Crick. Cistrons caught on; the term is still used today. Recons and mutons, two other types of genes proposed by Benzer, soon fell by the wayside, though, because it quickly became clear that they merely amounted to a single unit of DNA. Nevertheless, the very suggestion that biologists should think in terms of several senses of "gene" created fissures in the concept of a monolithic gene.

Meanwhile, a group of French geneticists, led by François Jacob and Jacques Monod, were showing that the gene's boundaries were fuzzier than bi-

ologists had thought. First, genes often act in clusters: Jacob and Monod portrayed "the" gene as a set of structural genes, which encode proteins, and regulatory genes, which switch the structural genes on and off in response to signals from the cell. Furthermore, Jacob and Monod showed that genes are not restricted to chromosomes. They found free-floating genetic elements, called episomes and plasmids, in bacteria; other scientists soon found these elements in higher organisms as well. Mitochondria, the cell's power plants, and chloroplasts in green plant cells were later found to have their own genes, inherited independently from those on the chromosomes.

In 1967 James Shapiro, an American then working at the University of London's Royal Postgraduate Medical School, and Sankhar Adhya, of the University of Wisconsin, discovered another wrinkle: regions of bacterial DNA that can cut themselves out of

> A group of French biologists, led by François Jacob and Jacques Monod, showed that the gene's boundaries are fuzzier than had been thought and that genes are not restricted to chromosomes.

one site on a chromosome and reinsert themselves at another site. They called these regions insertion elements. Twenty years earlier, Barbara McClintock, the great cytogeneticist of maize at the Carnegie Institution of Washington's Department of Genetics, had demonstrated that certain chromosomal elements—she did not believe them to be genes—can move, but

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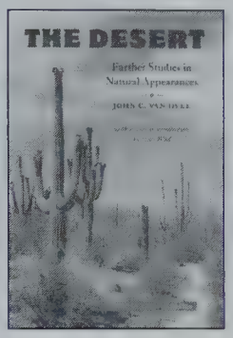

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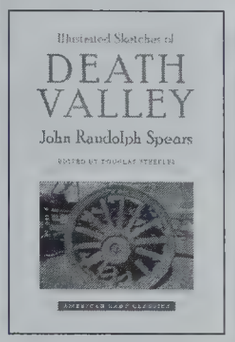

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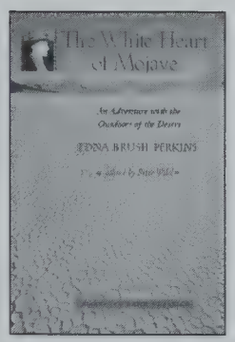

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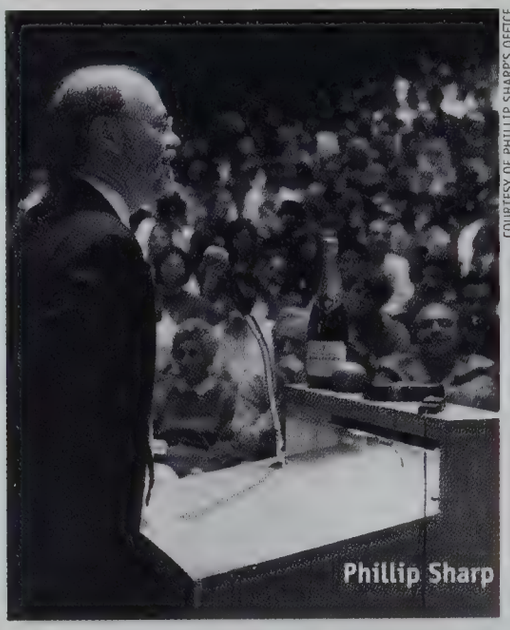
Jacques Monod, left; André Lwoff, center; and François Jacob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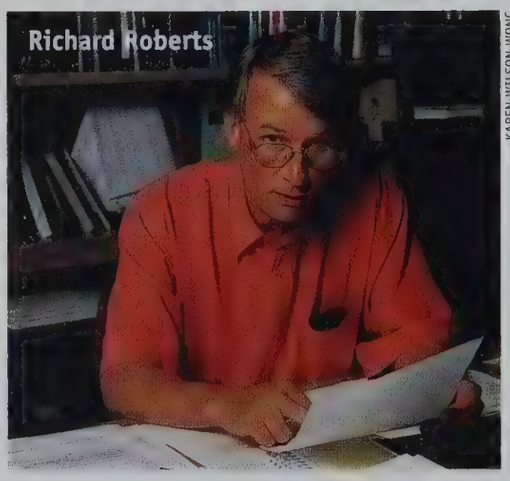
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BETTMANN ARCHIVE; CORBIS

Barbara McClintock

Shapiro and Adhya were the first to show how this movement takes place. Within ten years, insertion elements were found to be widespread in nature. Bacteria use them to pass along genes that confer resistance to antibiotics—which is one reason that drug-resistant strains of disease-causing germs spread so rapidly. Insertion elements enable retroviruses (HIV, for example) to incorporate their genes into their hosts' chromosomes. By 1980 biologists had accepted that certain genes routinely move around—within a chromosome, between chromosomes, within a species, between species. Movable genes torpedoed the idea of the gene as a site on a chromosome.

Today a reasonable working definition of a gene might read: one or more segments of DNA that specify a protein. The DNA is transcribed into an intermediary called RNA, which ferries the genetic message out to the ribosomes, where it is translated into a protein chain. This definition is a useful distillation of much that we learned about genes in the last century, but it is really just a starting point for thinking about all that a gene can be.

In 1977 two research groups, one led by Richard Roberts at Cold Spring Harbor Laboratory and the other led by Phillip Sharp at MIT, found that the many DNA segments that constitute a single gene are sometimes quite distantly separated on the chromosome. In such genes the segments are then spliced together to compose the RNA message. Furthermore, the same segments can be combined in different ways, which means that one gene is capable of specifying a whole family of products: one gene, sometimes several enzymes.

And the story gets even more complicated. Biologists have found examples of genes within genes and even overlapping genes. In some cases, the same DNA sequence specifies one protein when read in the "forward" direction and another when read "in reverse." Muddling things further, the instructions encoded in the DNA do not always reach the ribosome as a literal translation. In a phenomenon known as RNA editing, an enzymatic highwayman intercepts the RNA message en route and alters it, so the resulting protein is not identical to that specified by the DNA.

In a sense, as the reality of the gene has become more and more certain, the gene has again become an ideal, a measuring stick against which scientists compare the exceptions and deviations of real biology. Little wonder, then, that some writers, such as the historian and philosopher of biology Evelyn Fox Keller, have advocated scrapping the term "gene" altogether, in favor of some term or set of terms to better express the dynamism of the chromosomes. DNA is not made of discrete units with fixed boundaries; it comprises great lengths of sequence that are altered, shuffled, and reused. Perhaps Goldschmidt was right.

Yet the pendulum continues to swing. Some of the most exciting research in biology today employs devices known as DNA chips to provide snapshots of the activity of every gene in a cell. The chip, a square inch or less of glass or plastic, is first dotted with DNA from every gene in an organism. The genome—that interactive, responsive, deeply integrative set

of all the genetic material on the chromosomes—is then digitized as an orderly array of DNA microdots: one gene, one dot. Using special tracers, biologists can mark on the chip just those genes that are active at a given instant. Computers scan and analyze the chips, comparing the set of active genes both before and after various experimental manipulations. Thus, biologists can see which genes are activated in response to a specific procedure. It is an immensely powerful technique, one with promise for developmental biology, immunology, cancer biology, and drug discovery.

> Recently, biologists have found genes within genes, overlapping genes, and DNA sequences that specify one protein when read "forward" and another when read "in reverse."

This new research makes genes real once again by imposing physical boundaries between them. And so the pendulum completes another arc. But the world of science continues to revolve. As scientists probe genomes using DNA chips, they will, in all likelihood, find that our current notions about genes are inadequate, and the next swing of the pendulum will undoubtedly bring us to a new understanding.

Nathaniel C. Comfort is deputy director of the Center for History of Recent Science and assistant professor of history at The George Washington University in Washington, D.C. He is author of The Tangled Field: Barbara McClintock's Search for the Patterns of Genetic Control *(Harvard University Press, 2001).*

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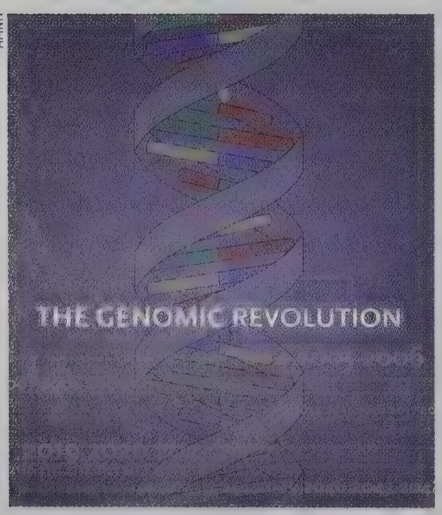
THE BEAST WITH FIVE GENOMES

Inside a termite's gut lives *Mixotricha paradoxa*, a microscopic organism comprising hundreds of thousands of smaller life-forms. *M. paradoxa* is an extreme example of how all plants and animals—including ourselves—have evolved to contain multitudes. By Lynn Margulis and Dorion Sagan

The hullabaloo over mapping the human genome—the sum of all the genes in an individual—might lead one to think that each species has only a single genome and that the genetic makeup of individual organisms is discrete and unitary. Such is far from the case. Paraphrasing Walt Whitman, we multicellular beings contain multitudes. All animals' cells have at least two interacting genomes. One is the DNA in the cell nucleus; this is the genome that has recently been "mapped." The other is that of the DNA in the mitochondria—the cell's multiple oxygen-breathing organelles that are inherited only through the maternal line. For more than a century, some scientists have known that every organism is in fact a multiple being, but until recently these unorthodox researchers were ignored.



AMNH

"THE GENOMIC REVOLUTION"
Opening May 26 at the American Museum of Natural History, a landmark exhibition explores the emerging role of genomics in science, technology, and everyday life. The exhibition runs through January 1, 2002.

In most of the animals we think we know best (mammals, reptiles, insects), the genomes that determine limbs, eyes, and nervous systems, for example, are very similar to our own. These animals, like us, are doubly genomic. Even some unicellular beings that do not have eyes, limbs, or nervous systems—such as amoebas and paramecia—contain both nuclear and mitochondrial genomes. Plants and algae have these double genomes as well, plus a third genome, of symbiotic origin. During their evolutionary history, they ingested (but did not digest) photosynthetic blue-green bacteria. Therefore, all visible photosynthetic organisms have at least three genomes. But many organisms—such as the protists that inhabit termites—contain within them up to five or more genomes.

The great nineteenth-century naturalist Joseph Leidy, one of the founders of the Academy of Natural Sciences in Philadelphia, was the first to take a close-up look at the contents of a termite's gut. "In

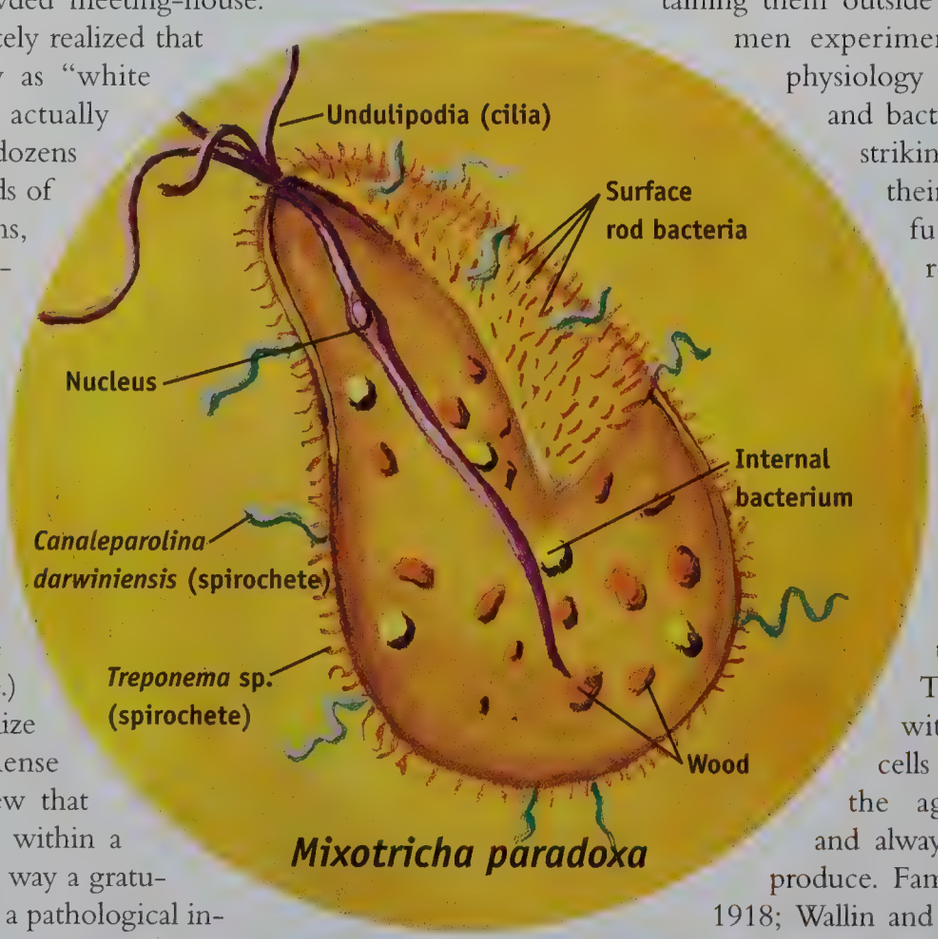
A termite's gut is a closed universe containing myriad microscopic organisms that enable it to digest wood. Found only within a particular Australian termite species, the protist *Mixotricha paradoxa* (inset) is in turn a composite being. Bacteria—thousands of small, hairlike spirochetes and hundreds of larger ones—cover its outer surface, enabling *M. paradoxa* to move, while thousands of spherical bacteria comprise its internal chemical workshop.

Illustration by Alexis Rockman

watching the Termites from time to time wandering along their passages beneath stones," he wrote, "I have often wondered as to what might be the exact nature of their food." What he saw under his microscope amazed him. If the termite's intestine is ruptured by the experimenter, he wrote, "myriads of the living occupants escape, reminding one of the turning out of a multitude of persons from the door of a crowded meeting-house."

The pioneering biologist Konstantin S. Merezhkovsky argued in 1909 that the little green dots in plant cells, which make sugar in the presence of sunlight, were originally separate organisms.

Leidy immediately realized that what he knew as "white ants" were actually composed of dozens of different kinds of tiny life-forms, including bacteria and what we now call protists. (Protists are microbes with nuclei; more complex than bacteria, the group includes amoebas, slime molds, and algae.) We now recognize that the immense and motley crew that Leidy observed within a termite is in no way a gratuitous add-on or a pathological infection. Rather, it is a necessary part of the termite's digestive system and is organized as a particular tissue: an aggregate working mechanism that turns the refractory compounds lignin and cellulose (the main constituents of wood) into food. This composite fabric, or living consortium, has evolved in the nearly oxygen-free closed system of the termite's abdomen for probably 100 million years; without the living, wood-degrading factories that have become their digestive systems, these termites starve.



The pioneering biologist Konstantin S. Merezhkovsky first argued in 1909 that the little green dots (chloroplasts) in plant cells, which synthesize sugars in the presence of sunlight, evolved from symbionts of foreign origin. He proposed that "symbiogenesis"—a term he coined for the merger of different kinds of life-forms into new species—was a major creative force in the production of new kinds of organisms. A Russian anatomist, Andrey S. Famintsyn, and an American biologist, Ivan E. Wallin, worked independently during the early decades of the twentieth century on similar hypotheses. Wallin further developed his unconventional view that all kinds of symbioses played a crucial role in evolution, and Famintsyn, believing that chloroplasts were symbionts, succeeded in maintaining them outside the cell. Both men experimented with the physiology of chloroplasts and bacteria and found striking similarities in their structure and function. Chloroplasts, they proposed, originally entered cells as live food—microbes that fought to survive—and were then exploited by their ingestors. They remained within the larger cells down through the ages, protected and always ready to reproduce. Famintsyn died in 1918; Wallin and Merezhkovsky were ostracized by their fellow biologists, and their work was forgotten. Recent studies have demonstrated, however, that the cell's most important organelles—chloroplasts in plants and mitochondria in plants and animals—are highly integrated and well-organized former bacteria. Using

new methods, scientists have been able to raise and resolve the question of how these bacteria became permanent symbionts.

Like other animals, we harbor in our intestines an assortment of specific microbes that help us digest food, although some are also able to live outside humans. Few of our microbes are organized as layers of tissue, as they must be in termites. Nevertheless, without these hitchhikers to help digest fiber and produce vitamins, we—like termites—weaken and even die. Entirely integral to our bodies, however, are the mitochondria in our nucleated cells. These tiny entities use oxygen to generate the chemical energy needed to sustain life. They reproduce on their own, independently of the nuclear DNA, and multiply more quickly after short bursts of muscular exercise, leading to stronger, more mitochondria-packed muscles. Because mitochondria are so genetically integrated into each of our cells, no one has yet succeeded in growing them in test tubes.

Acceptance of the composite nature of the individual revolutionizes evolutionary biology. Bacteria are exemplary genetic engineers: splicers and dicers and mergers of genomes par excellence.

We believe that Wallin and Merezhkovsky were fundamentally correct when they claimed that all nucleated living things evolved by symbiogenesis, generally because of preexisting bacterial genomes physically associated with other organisms. Reef-building corals, for instance, are now known to have five different genomes of once independent organisms. And *Mixotricha paradoxa,* a compound beauty found in a termite's gut, also has five genomes. Indeed, *M. paradoxa* could well be the "poster animal" for symbiogenesis.

In 1933 Australian biologist J. L. Sutherland first described and named "the paradoxical being with mixed-up hairs" (she mistakenly thought it was the only microbe that swims by simultaneously using both flagella and cilia). Studies done by A. V. Grimstone of Cambridge and the late L. R. Cleveland of Harvard in the 1950s with the electron microscope showed that *M. paradoxa* was a hundred times larger than its close relatives, that four different kinds of bacteria were part of its body, and that it lacked mitochondria.

For many years, we have studied and photographed this organism. Under low magnification, *M. paradoxa* looks like a single-celled swimming ciliate. With the electron microscope, however, it is seen to consist of five distinct kinds of creatures. Externally, it is most obviously the kind of one-celled organism that is classified as a protist. But inside each nucleated cell, where one would expect to find mitochondria, are many spherical bacteria. On the surface, where cilia should be, are some 250,000 hair-like *Treponema* spirochetes (resembling the type that causes syphilis), as well as a contingent of large rod bacteria that is also 250,000 strong. In addition, we have redescribed 200 spirochetes of a larger type and named them *Canaleparolina darwiniensis.*

Acceptance of the composite nature of individuals, we predict, will soon revolutionize evolutionary biology. Bacteria are exemplary genetic engineers: splicers and dicers and mergers of genomes par excellence. Devoid of immune systems, always reproducing without mate recognition, bacteria are supremely promiscuous beings in which infection and sex—that is, gene flow—are virtually the same thing. The sexual proclivities of bacteria include (when their survival is threatened) rampant exchange of genes—next to which our own species' most bacchanalian orgies look like rather subdued affairs.

Biologists have always puzzled over why there are so many kinds of beetles. Perhaps symbionts beneath the surface, generating variety at the genomic level, account for nature's beetlemania. Insects have integrated bacterial genomes to an extraordinary degree. In many cases, bacteria reside in all the tissues, accumulate in the eggs, and are inherited. Beetles have developed partnerships with an extremely diverse assortment of bacteria; many more kinds live inside their tissues than live in most other groups of animals.

Eventually we may well realize that natural selection operates not so much by acting on random mutations, which are often harmful, but on new kinds of individuals that evolve by symbiogenesis. Scrutinizing any organism at the microscopic level is like moving ever closer to a pointillist painting by Georges Seurat: the seemingly solid figures of humans, dogs, and trees, on close inspection, turn out to be made up of innumerable tiny dots and dashes, each with its own attributes of color, density, and form. □

VICTORIA AND ALBERT MUSEUM, LONDON; ART RESOURCE, NY

SEX, ERRORS, AND THE GENOME

Can human beings keep evolving? Or does the error-ridden process of reproduction prevent us from getting more complex than we already are?

By Mark Ridley

When extraterrestrial visitors land on Earth in their space saucer, they will be excited to see that ours is one of those rare planets on which complex life has evolved. They will already have found microbes—organisms resembling our viruses and bacteria—on every other life-bearing planet. And they will know that the real fun begins not in trying to understand how life on Earth came to exist at all but in how such complex forms as humans and butterflies and clams and whales and trees came about. And a question they will certainly ask is, How many copying mistakes does earthly life make when it reproduces the hereditary molecules of its DNA code?

When we (and other life-forms) produce offspring, our genome—the sum of all our individual DNA—is copied. But the repeated copying that takes place prior to pregnancy, during numerous divisions of our reproductive cells, can alter the messages in our genome—much as the children's game of Chinese Whispers (called Telephone or Gossip in the United States) distorts a verbal message as it is repeated from one person to the next. By the end of the line in Chinese Whispers, the message is laughably corrupted.

In sexual reproduction, a male's and female's genomes are reshuffled, increasing the odds that some offspring will be produced without serious DNA copying errors.

Rajah Bhup Singh of Guler under a quilt with his rani, ca. 1800

Through 3.5 billion years of evolution, life-forms have been able to perpetuate themselves—and become more complex than their ancestors—partly because they evolved ways of dealing with these copying errors. Double-stranded DNA (which appeared quite early in the history of life) and certain enzymes work within the cell nucleus to prevent errors from happening in the first place. Other enzymes correct most of the errors that nonetheless arise: proofreading and repair enzymes correct errors in the code, and developmental troubleshooting enzymes correct the expression of a faulty code without correcting the code itself. But the most important factor in the evolution of complex forms, which contain many genes (and therefore the possibility of making many errors), was the evolution of sex. Because sex takes one set of genes from each parent and recombines them, it shuffles the errors that manage to slip through all the defenses and improves the odds that at least some healthy, error-free offspring will result. This crucial innovation probably arose about 2 billion years ago, around the time that a more complex cell type—called the eukaryotic cell—originated.

Nonetheless, human beings are quite error prone. When we copy our DNA, we make more mistakes than most, if not all, other forms of life on Earth. In fact, every human being is conceived in 200-fold copying error. How many of these 200 mutations are harmful is not known. Most errors seem to be neutral, and a very few may actually help the organism, but even rigorous accounting cannot squeeze the harmful-error rate to below about 2 per conception. A figure of 5 to 10, or even 20, harmful mutations per conception may be quite likely. These high numbers are a consequence of our complexity. A human being contains 30,000 genes, included within a total of some 6.6 billion or

Based on the forthcoming book The Cooperative Gene, *by Mark Ridley.* *Copyright © 2001 by Mark Ridley. To be published by The Free Press, a division of Simon and Schuster, Inc., N.Y. Adapted with permission.*

MUTATIONS: MOTHER VERSUS FATHER

As their life spans stretch out, men and women travel different evolutionary roads, and the amount of DNA copying that goes on in their gonads contributes to the error level of their genomes in different ways. Men manufacture sperm throughout their lives. About 40 cell divisions in the reproductive cells have occurred in a human male by the time he reaches puberty. After that, the DNA in his sperm is copied every sixteen days, or 23 times per year. A twenty-year-old man's genome has been copied more than 200 times, and a forty-year-old's more than 600 times. Compare that with the average adult male rat: its DNA has been copied only 58 times in its short life, and the DNA in its spermatozoa is therefore relatively error free.

A female human, on the other hand, already possesses her lifetime supply of eggs—with about 33 cell divisions behind them—by the time she is a late-stage fetus. When a thirty-year-old man breeds with a thirty-year-old woman, his DNA has been copied 430 times against her 33. With about thirteen times as many errata in his DNA, about 185 of the 200 copying mistakes in each human conception may come from the sperm. However, a woman's eggs are more likely to carry serious errors in chromosome numbers, and these errors increase with maternal age. Some disorders, such as Down syndrome, are the result of eggs that deliver the wrong number of chromosomes during conception.

All the DNA messages in a sperm and an egg can be compared with all the text in two sets of encyclopedias. If publishers made errors in book production at the same rate fathers and mothers do in transcribing their DNA, buyers of *Britannica* would receive sets with 200 printing errors on average, and half the time they'd be sent the wrong number of books.

more units of DNA. A bacterium might have on the order of 2,000 genes and 2 million units of DNA. The unit error rate, however, is similar in humans and bacteria. Humans therefore make more mistakes than bacteria do, for much the same reason that a scribe is more likely to make mistakes when copying the Bible—a job that took about a year and a half in the Middle Ages—than when copying a single psalm.

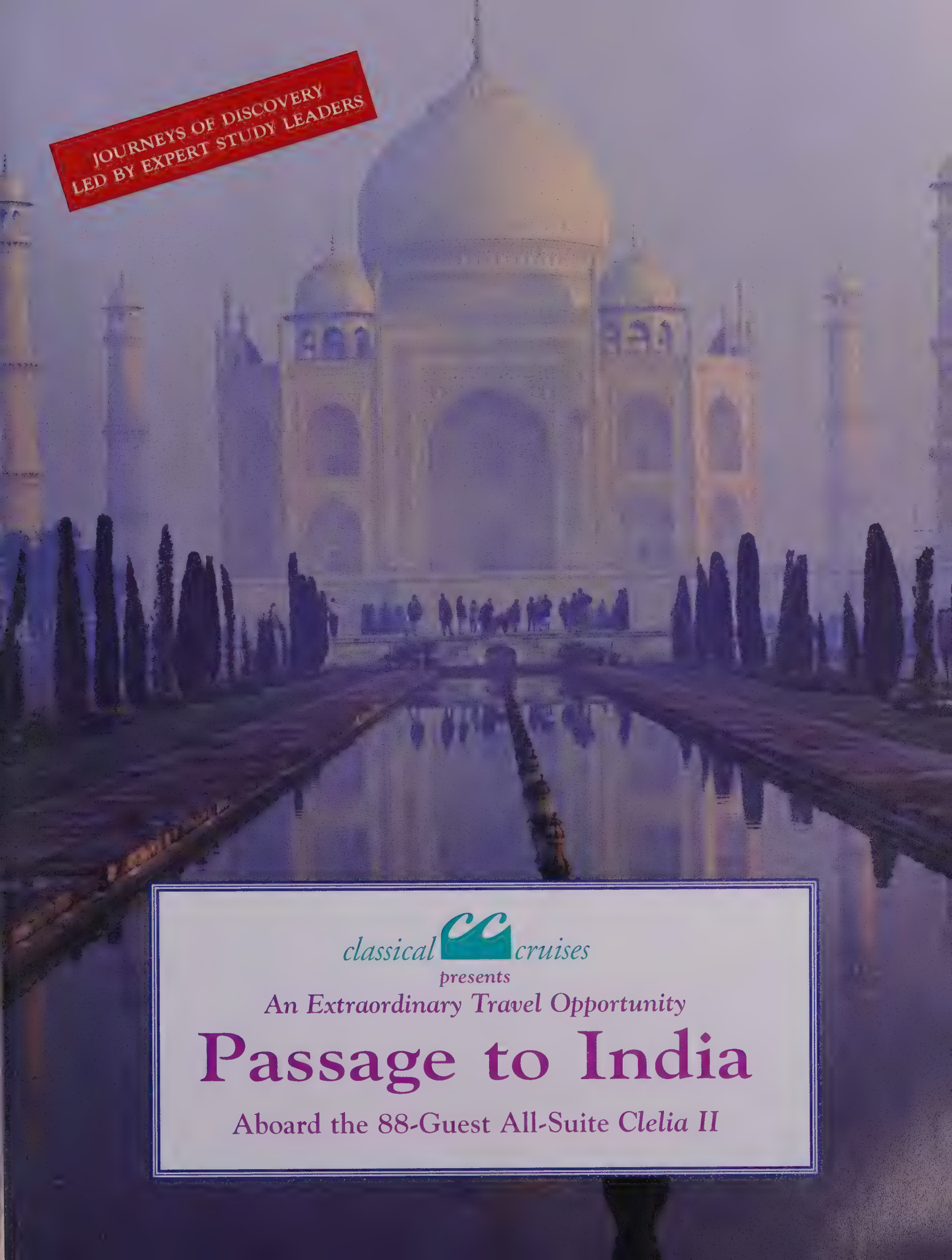
Another, and perhaps even more important, reason we humans are error prone is that we are long lived, with an average of thirty years between one generation and the next. Mutation rates are higher in long-lived animals such as humans because we copy our reproductive DNA a number of times in the interval between when we ourselves are conceived and when we beget our own children. (See "Mutations: Mother Versus Father," above.) And—complicating matters further—not only do most human embryos contain about 200 copying errors, or "typos," in individual DNA messages, but about 50 percent of these conceptions have a botched number of chromosomes. The length of a typical generation is probably a factor here, too, because the percentage of such errors in rabbits or guinea pigs—with generations measured in weeks or months—is negligible. Even if half of all embryos have chromosomal errors, that still leaves 50 percent that are potentially available to carry the human species forward. And these will of course have, on average, 2 to 20 damaging typos.

Any individual may produce some faulty young, but for humans or any sexually reproducing form of life to persist, the average parent must produce at least one error-free offspring. Luckily, in addition to having enzymes that prevent or correct copying errors, we also have sex, which provides each offspring with a helpful redundancy of genes. In fact, our cells contain four copies of the information for each genetic instruction—a paternal and a maternal double helix. A correct version in one set will usually override a copying mistake in the other, so the average parent has a reasonable chance of producing a baby that will itself survive to reproduce. Unfortunately, sexual reproduction does not always prevent an embryo from picking up a whole extra chromosome or two. In this case, natural selection comes into play after conception: embryos with the wrong number of chromosomes almost always die in the very earliest stages of their intrauterine existence. (Those who have extra chromosomes but do survive, such as people with Down syndrome, often have significant health problems.)

What implications does our high error rate have for human evolution? Can we keep on evolving

AT CONCEPTION, HUMAN EMBRYOS AVERAGE ABOUT 200 COPYING ERRORS, AND 50 PERCENT OF THE EMBRYOS HAVE A BOTCHED NUMBER OF CHROMOSOMES.

and pick up more genes for more functions? How high can the error rate go if a sexually reproducing life-form is to be indefinitely sustainable? Equations have been written to address this question, but the real answer remains unknown.



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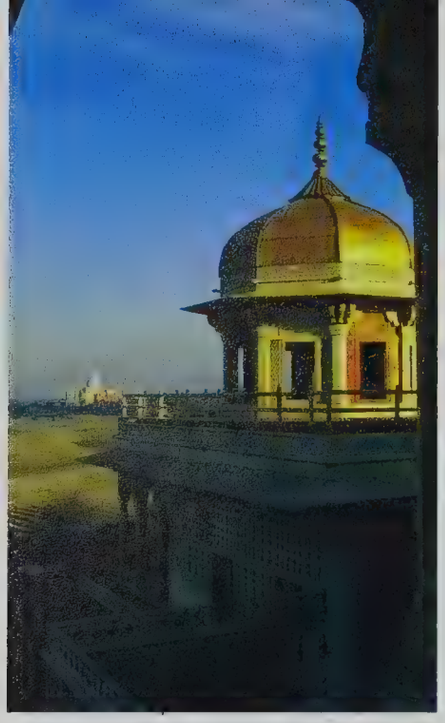
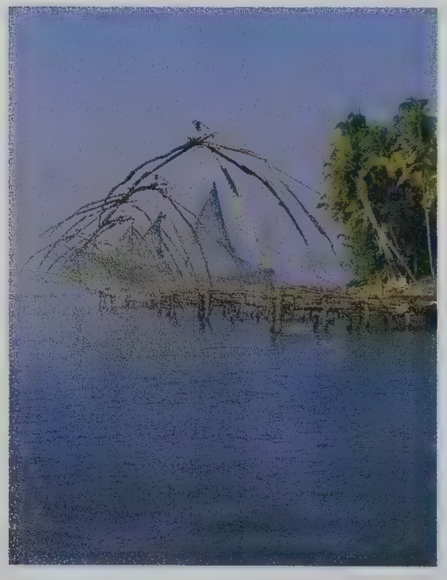


Red Fort, Agra

Decorated Elephant, Goa



Fishing Nets, Cochin

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Study Leaders

Annapurna Garimella

Departure: *February 12 - March 2*

A native of India, Annapurna Garimella is a specialist in Indian and Islamic art and architecture. A graduate of Columbia University, where she received her Ph.D. in art history, she was curator of the exhibition *Saris of India* at California State University Northridge, and documented paintings and wrote interpretive materials for the 1998 exhibition *Sakki: Friend and Messenger in Rajput Love Paintings* at the Sackler Gallery of Art. She is currently researching modern Indian religious architecture as a Visiting Fellow at the Center for the Study of Culture and Society in Bangalore, India.

To Be Announced

Departure: *February 19 - March 8*

James Clad

Departure: *February 26 - March 16*

James Clad holds the Henry R. Luce Foundation Research Professorship of Southeast Asian Studies at Georgetown University. A diplomatic officer posted in India from 1976-77, Professor Clad chaired the "Georgetown India Forum" last year. His views on India and Indonesia are frequently quoted in leading newspapers nationwide, and he regularly appears as guest commentator on Asia issues for National Public Radio, CNN, and CNBC.

Damodar R. Sardesai

Departure: *March 5 - 22*

Professor Emeritus of Indian History at the University of California, Los Angeles, Damodar Sardesai has written over a dozen books, including *India Through the Ages*, and more than 200 articles, papers, and book reviews. Among many academic honors, he has received honorary fellowships to the Royal Historical Society in 1979, Father Heras Society of Bombay in 1991, and was elected President of The Asiatic Society of Bombay in 1989.

Itinerary

Day 1
USA | DEPARTURE

Day 2
EN ROUTE

Day 3
DELHI, INDIA
Arrive in Delhi and transfer to the *Taj Mahal Hotel*. Afternoon tour of New Delhi.

Day 4
DELHI
In the morning, explore Old Delhi. Tour the Red Fort, built by Mughal Emperor Shah Jahan as his royal residence; the Jami Mosque; and the Raj Ghat, the memorial to Mahatma Gandhi. This afternoon, visit the National Museum and its extensive collection of artifacts.

Day 5
DELHI | SIKANDRA | AGRA
This morning, visit Akbar's Mausoleum, an extraordinary work of architecture blending Hindu, Christian, Islamic, Buddhist, and Jain motifs. Continue to Agra and transfer to the *Jaypee Palace Hotel*. Later in the afternoon, tour the massive Agra Fort.

Day 6
AGRA | TAJ MAHAL | FATEHPUR SIKRI
This morning, visit the incomparable Taj Mahal. This afternoon, tour the abandoned yet perfectly preserved Mughal city of Fatehpur Sikri.

Day 7
AGRA | BHARATPUR | JAIPUR
Drive to renowned Keoladeo National Park this morning. Later in the afternoon, arrive at Jaipur for a two-night stay.

Day 8
JAIPUR
Tour Jaipur, including the Hawa Mahal, or Palace of the Winds. Continue to the Amber Fort. Also visit the Jantar Mantar Observatory and City Palace.

Day 9
JAIPUR | MUMBAI (BOMBAY)
Board a morning flight to Mumbai. In the afternoon tour the Prince of Wales Museum, Victoria Terminus, Marine Drive, Chowpatty Beach, and the Municipal Dhobi Ghats. Accommodations are at the *Hotel Taj Mahal*.

Day 10
MUMBAI | EMBARKATION
Enjoy an excursion by local boat to Elephanta Island, the small island famous for its eighth-century temple caves carved out of rock. This afternoon, transfer to the port to embark *Clelia II*.

Royal Botanic Gardens, Peradeniya

Day 11
GOA
After a morning at sea, arrive in Panaji for an excursion to Old Goa.

Day 12
MANGALORE | MUDABIDRI | KARKALA | MANGALORE
From Mangalore an excursion leads to several revered Jain shrines that attract pilgrims from all over India, including Chandranatha Basti, with an imposing entrance gate and two large columned halls, and Chaturmukha Temple, noted for its symmetrical proportions.

Day 13
AT SEA

Day 14
TUTICORIN | TIRUNELVELI | TIRUCHENDUR | TUTICORIN
Morning arrival in Tuticorin, once a thriving Portuguese colony. In Tirunelveli visit the 13th-century Nellaiyappa Temple. After lunch, continue to Tiruchendur to explore the Subramanya Temple, one of South India's most sacred temples.

Day 15
COLOMBO, SRI LANKA | KANDY
Call at Colombo for an excursion to Peradeniya to see its beautiful Royal Botanic Gardens. Continue to Kandy and the lake-front Temple of the Tooth, which enshrines what is said to be a tooth of the Buddha. We also tour the Archaeological Museum, with its superb collection of sculptures and other objects.

Day 16
AT SEA | COCHIN
After a day at sea arrive in Cochin, the oldest European settlement in India.

Day 17
COCHIN | DISEMBARKATION
Explore via local boats the backwaters of Cochin to observe typical village life. Afternoon at leisure. This evening, attend a performance of the centuries-old Kathakali dance theater. Accommodations are at the *Taj Malabar Hotel*.

Day 18
COCHIN | USA
In the morning, tour the old districts of Mattancherry and Fort Cochin. After lunch, transfer to the airport for the return flight to Mumbai to connect with the flight to the United States.

Day 19
ARRIVE USA

Departures

Depart	Return
February 12, 2002	March 2, 2002
February 19, 2002	March 8, 2002*
February 26, 2002	March 16, 2002
March 5, 2002	March 22, 2002*

* The cruise on these departures operates in the reverse direction, Cochin-Mumbai.

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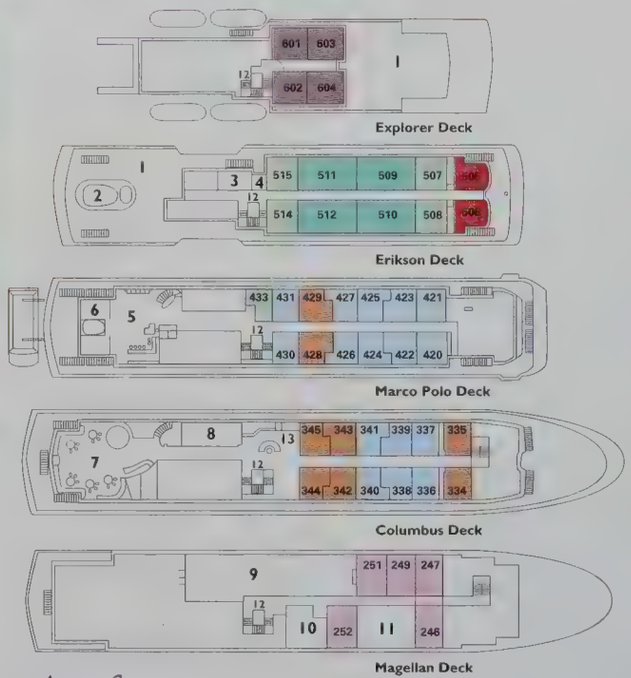

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A complacent conclusion can be drawn if we assume that sexual reproduction—with its ability to compensate for errors—has dramatically raised the upper limit on copying mistakes. If it has done so, then natural selection can easily take care of all the harmful mutations, and *Homo sapiens* is evolutionarily motoring along with more important worries than mutational error.

Another possibility is that the harmful-error rate has already reached an upper limit and we are in a mutational meltdown. This scenario is not only apocalyptic but unlikely. Our ancestors have probably been making 200 copying mistakes per offspring and putting the wrong number of chromosomes in 50 percent of them ever since the span of one hominid generation evolved to the modern figure of thirty years or so. Experts disagree about when this happened. Some argue that chimpanzees and gorillas have a generation time roughly similar to ours (between twenty and thirty years), which would push the origin of that trait back near the origin of great apes, to about 15 million years ago. Others would use a figure nearer 5 million years ago, when the human line branched off from that of the other great apes. Or, if our modern generation length dates back to the origin of the genus *Homo,* maybe a figure of 2 million years would be better. If we have been just fine for 15 million years, we'd have to conclude that our mutation rate is truly sustainable. There is some evidence to suggest that we are accumulating mutant genes at a higher rate than are other species, but I suspect that our mutation rate is older than we are and is similar to that of chimps and gorillas. We are probably not mutating our way to inevitable extinction.

What does an understanding of genomic error tell us about what we can expect from the new human reproductive and genetic technologies? Such a discussion is futuristic and necessarily uncertain and conditional, but the way we understand evolution, error, and complexity does bear on the answers.

One potential reproductive technology that has aroused tremendous interest is cloning. Although full reproductive cloning—in which an individual

Perhaps our species would be unharmed if we disposed of sex, but it would be a good idea to find out first.

Amorous couple in bed, terracotta, Old Babylonian period, ca. 1750 B.C.

ERICH LESSING/ART RESOURCE, NY

produces an offspring made from an exact copy of the DNA in his or her sperm or egg cells—might be used by a minority of human beings who have no other reproductive options, I suspect the practice is highly unlikely to become widespread. The reason is simply that cloning has a drawback: it suffers from as many errors as sexual reproduction does but lacks a crucial mechanism (sex itself) for clearing out the errors. If a subset of human beings signed up to use only clonal reproduction in the future, they would also be signing up their progeny for rapid genetic decay. Mutations would accumulate much faster than they could be eliminated. Not many generations would pass before all the clones were so loaded with genetic defects that they could not survive. (See "Why Sex Is Better Than Cloning," page 49.)

At this stage of our understanding, opting to reproduce by cloning is rather like what volunteering for a heart transplant would have been during the era before the function of the immune system was known. The problem lies in messing with a design feature of our bodies when we do not know the design principles. Whatever factors allowed sexual reproduction to evolve, the advantages they conferred must have been big. Otherwise, the sexual form of life—in which each being is able to pass on only half its genes—would never have evolved in the first place. The lower reproductive rate is probably made up for by a difference in quality: the average sexual offspring is probably twice as good as the equivalent cloned offspring. In other words, sex may have evolved for some reason that we are clueless about, and perhaps our species would be unharmed if we disposed of it. But it would be a good idea to find out first.

Gene therapy, however, may be another story. Gene therapy means medically curing a defective gene by replacing it with a normal version, or by neutralizing it, or by some other technology yet unimagined. The use of such technology will, I expect, prove to be as acceptable as conventional medicine is now. (The idea of gene enhancement—in which an individual's genes are replaced with the aim of improving physical appearance and athletic, mental, or other abilities—will remain controversial.) If one is carrying a gene for a condition such as Tay-Sachs disease, deciding to undergo gene therapy may someday be much easier than the only options currently available: deciding not to have children at all, aborting a fetus that inherits the defect, or giving birth to a baby with an incurable illness. Such decisions are ghastly, and it therefore seems likely that people will use the new technologies to cure genetic error. Of course, these practices have not yet been shown to be safe for humans. And in any case, we cannot now do much with gene therapy, relative to its potential. In absolute terms, geneticists have identified a large number—

THE RISK OF HAVING A SCHIZOPHRENIC CHILD IS THREE TIMES GREATER FOR FIFTY-YEAR-OLD FATHERS THAN FOR FATHERS UNDER TWENTY-FIVE.

maybe in the hundreds, maybe in the few thousands—of defective genes, but this is probably only the tip of the iceberg. Every one of a human's 30,000 or so genes will have several mutant, defective versions. Defects also exist in pieces of DNA that do not code for genes.

Whatever the benefits of gene therapy, the future may also bring technologies for preventing copying errors in the first place, thus eliminating the need for repair. Consider the idea of freezing gametes (or preserving them by some other method). In women, the quality of egg cells tends to decline with time. The possibility that a twenty-year-old mother will conceive a baby with an extra chromosome is negligible; the chance that a forty-year-old mother will do so is several percent; and soon after that, the biological clock reaches midnight. In the future, however, we may be able to stay the clock hands. Young women could opt to have some reproductive cells removed and softly embalmed, and then have them revived for pregnancy at a time of their own choosing. One consequence would be a reduction in the mutation rate in individuals (and in species, in proportion to the number of individuals who choose this procedure). Indeed, the mutation rate might be further reduced by harvesting the cells as early as possible—at birth, for example. Of course, the trade-off here would involve particularly knotty ethical problems (the impossibility of getting informed consent being the

If a life-form is to persist, the average parent must produce at least one error-free offspring.

Detail from *Offering to Venus*, by Titian, ca. 1518

most obvious). Men, too, could freeze their gametes. An old man's sperm contains so many mutations that the geneticist James F. Crow once joked that the greatest threat to the human genetic future is fertile old men. The broad consequences, if any, of freezing sperm are uncertain, but a recent U.S. study found that fathers over fifty run three times the risk of having a child that develops schizophrenia than do fathers under twenty-five.

Could we ever evolve to be more complex? It's hard to say, and it depends on whether research proves that sexual reproduction is up to the task of

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THE ANDY WARHOL FOUNDATION FOR THE VISUAL ARTS/ ART RESOURCE, NY. COPYRIGHT© ARS, NY.

clearing the errors that would be created by an organism with a longer life, a longer generation time, or a larger genome. Early in the history of microbial life, the evolution of repair enzymes helped reduce the copying-error rate from about 1 in 10,000 to about 1 in 10 billion. If gene therapy by itself could be used to cure a large proportion of human genetic defects, it could become the cultural equivalent of those repair enzymes. The introduction of new gene and reproductive technologies could turn out to be not just a way to prevent individual heartbreak but one of the most momentous events in the 2-billion-year history of complex life. It would rate with the handful of evolutionary breakthroughs: reliably replicating molecules, repair enzymes, the Mendelian machinery of inheritance, and the evolution of sex and gender.

Such a breakthrough in reducing error rates might permit the evolution of forms with a whole new level of complexity—in intellect or social organization, for example. But what might such a life-form look like? Thirty thousand genes of DNA code give you a complex being such as a human or a mouse, but what would 100,000 give you? Since education in our information-based society uses up a large fraction of the human life span, perhaps we could evolve to live longer. Or we might evolve more efficient learning abilities. Our skill in acquiring language between the first and second year of life is impressive, but genetic programming for early learning probably involves a large number of genes. With extra genes at our disposal, we could acquire other skills the same way, with our brains prompting us in the right direction. Each skill would have its own set of DNA codes. We could then pick up computer programming, for example, or methods of pricing derivatives on the futures market, the way we learn to understand and speak our own languages.

GENE THERAPY COULD BECOME ONE OF THE MOST MOMENTOUS DEVELOPMENTS IN THE HISTORY OF COMPLEX LIFE.

Unlike sex, cloning has the drawback of creating copying errors that cannot be corrected.

***Large Triple Elvis,* by Andy Warhol, 1963**

Being brainier, however, may not be the best way to become more complex. I have in mind another fanciful idea, inspired by the late evolutionary theorist W. D. Hamilton. If 30,000 genes are needed to code for a human being or a bird, and 20,000 to code for an oak tree or a lobster, 100,000 might code for all four. The resultant organism would not combine the features of all those organ-

WHY SEX IS BETTER THAN CLONING

All reproduction gives rise to some mutations, or errors, during the copying of DNA messages. Sexual reproduction, which operates according to Mendel's principles of inheritance, has the advantage of redistributing the parents' mutations among the offspring. In effect, a toss of the coin determines whether any particular gene will be "allowed" into each embryo. Meiosis is the fateful cell division in which each gene, whether perfect or mutated, has only a 50-50 chance of making its way into a gamete—a particular sperm or egg. On average, if a male or female with one harmful DNA mutation produces eight gametes, four will have the flaw and four will be free of error. When the sperm and eggs of two parents—both of whom have one harmful mutation—are combined to form eight new organisms, four offspring on average will have one harmful mutation and two will have two, but the remaining two will have no mutations at all. The life-form carries on.

Now consider a clonal life-form. If a parent with one harmful mutation decides to have eight offspring, all eight will inherit the flaw. A life-form that reproduces this way will continue to accumulate errors each time its DNA is copied; over several generations, it becomes unsustainable and will be destroyed by its mutations. Though some life-forms—certain plants, for example—use clonal reproduction, they also have sex from time to time. On the family tree of complex life, only a few odd twigs are exclusively clonal.

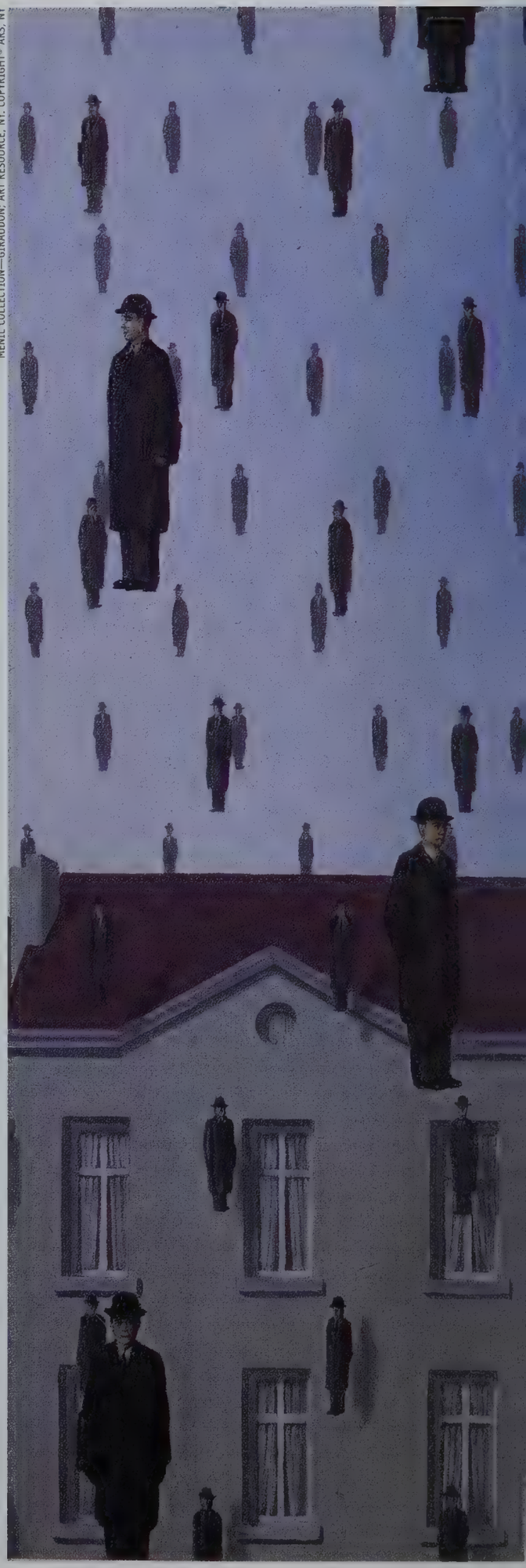
Another reason to doubt we could go in for cloning in a big way is that sex is probably a necessary condition for complex life. This conclusion would stem from the theory (put forward by Alex Kondrashov, of the National Center for Biotechnology Information) that sexual reproduction evolved primarily to purge bad genes. Another plausible theory is that sex exists to keep us from being destroyed by parasites and microbial pathogens. Since infectious bacteria, as well as viruses and parasitic protozoans, evolve rapidly as they exploit our bodies as habitats, we need to make genetic shifts in each generation to keep up with them. Even if the parasite-avoidance theory is a better explanation for why sex evolved, cloning would still be a bad idea. Your cloned offspring would be more likely to die of infectious disease rather than genetic disease. Cloning yourself would be like taking your children to a plague-stricken city, where the chance that they will die of plague is doubled.

isms; such a monstrous body would have hopelessly difficult integration tasks. What the extra genes might provide is the opportunity to choose which life-form to become. At some embryonic stage, our large-genomed creature could assess its environment and see where the best opportunities lay. If a niche for oak trees was relatively unoccupied, it could commit to this form and grow up as a tree that produces acorns. If the sea bottom was underexploited, it could grow claws, eight legs, and a spring-action tail—and watch out for lobster pots. Unconstrained by the form of its parents, the embryo would pick the adult form that promised the best reproductive return. The embryo itself would be a complex creature, because it would have to assess all those environments and opportunities. It might start out in larval-assessor form and then undergo a metamorphosis as it switched on all the necessary genes for its preferred adult form. All the unused genes would simply be switched off, perhaps until the next generation.

But there may be many reasons such a flexible form has not evolved. An important one is that natural selection—creating a massive slaughter of mutants in every generation—is needed to ensure that genetic information is not erased by mutational decay. If genes are not expressed, natural selection cannot work on them. Put another way, if a gene is not used, it is lost over evolutionary time.

The destructive force of mutation has prevented earthly life from evolving reserves of occasionally expressed genes. But what if that force were relaxed or resisted? If future technology could accomplish this, or if an otherworldly method of reproduction superior to Mendelian inheritance emerged, life could add to its reserves of DNA. The future would lie with life-forms that, although not necessarily more intelligent than humans, might have genetic subroutines that could be called up as appropriate. After fire and brimstone, such descendants could reinvent themselves as fire-adapted flowers and cover the scorched Earth with fresh foliage. After the deluge, they could grow up as fish and swim safely beneath the waves. □

If we evolved extra genes, we might acquire computer skills as effortlessly as we pick up our native language.



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***Golconde,* by René Magritte, 1953**

Magritte

BACTERIAL REVELATIO

Genomics is providing a wealth of information about some of Earth's littlest, oldest, and most abundant living things.

Story by Roberta Friedman ~ Illustrations by Robert Grossman

Pumping Metal

How do certain bacteria subsist amid heavy metals, oils, and rank toxic sludge—substances that kill most other forms of life? Genomics may help researchers answer this question and, as a result, aid in the cleanup of humanity's nastiest messes.

One bacterium that may be useful in mopping-up operations is *Ralstonia metallidurans.* Through its ability to turn normally poisonous heavy metals into harmless carbonates, this bacterium has the potential to make the environment safe for other forms of life that lack its transformational powers. Since the carbonates accumulate on the surface of *R. metallidurans,* if these microbes are allowed to work for a while and are then removed, the heavy metals can be effectively removed with them.

METAL-MINING MICROBE

Last October, as part of its first annual "Microbial Month," the U.S. Department of Energy's (DOE's) Joint Genome Institute in Walnut Creek, California, sequenced the genomes of fifteen bacteria. One was *R. metallidurans*. Although not finalized, the sequences give researchers a good idea of how this microbe survives and even thrives in the most hostile environments. The DOE's draft of this organism's 3,000 genes may in fact reveal the secret of some microbes' ability to pump heavy metals and precipitate them harmlessly.

The genes that confer *R. metallidurans*'s resistance to heavy metals are on a circular bit of DNA called a plasmid. Plasmids are the shuttle buses of the bacterial genetic world, easily transferring genes among microbes—even across species. And according to John Dunn, a biologist at the DOE's Brookhaven National Laboratory, *R. metallidurans*'s plasmids are about ten times the usual size.

Before Microbial Month, only one percent of this bacterium's genome had been known. Now, because of the DOE-led effort, scientists can contemplate, for example, adding genes to *R. metallidurans* that would link its uptake of heavy metals to biolumines-

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cence. Glowing bacteria could then indicate the presence of heavy-metal contaminants. Researchers might also be able to effect the transfer of *R. metallidurans*'s pumping instructions to other bacteria, or to use it as a host for other genes that could improve upon its talents.

The very flexibility of the *R. metallidurans* genome is what allows it to adapt nimbly to changing and challenging environments, says Dunn. Of course, tinkering with such a mobile microbial genome raises concerns, and scientists working on the organism do not propose to release altered genomes without first amassing adequate knowledge of the habits these bugs might adopt. To that end, Dunn expects that within a year, the full genome of *R. metallidurans* will be mounted for study on a DNA microarray chip. Even with microarrays—which will allow scientists to take snapshots of the microbe's genes in action—it will be some time before the story of *R. metallidurans*'s lifestyle is unraveled.

By the Light of the Sea

Efforts to probe marine ecosystems have always been hampered by the difficulties of exploring the open ocean. But now that the science of genomics is making possible the decoding of complete genetic blueprints, researchers are quickly moving toward a more comprehensive understanding of the marine food chain.

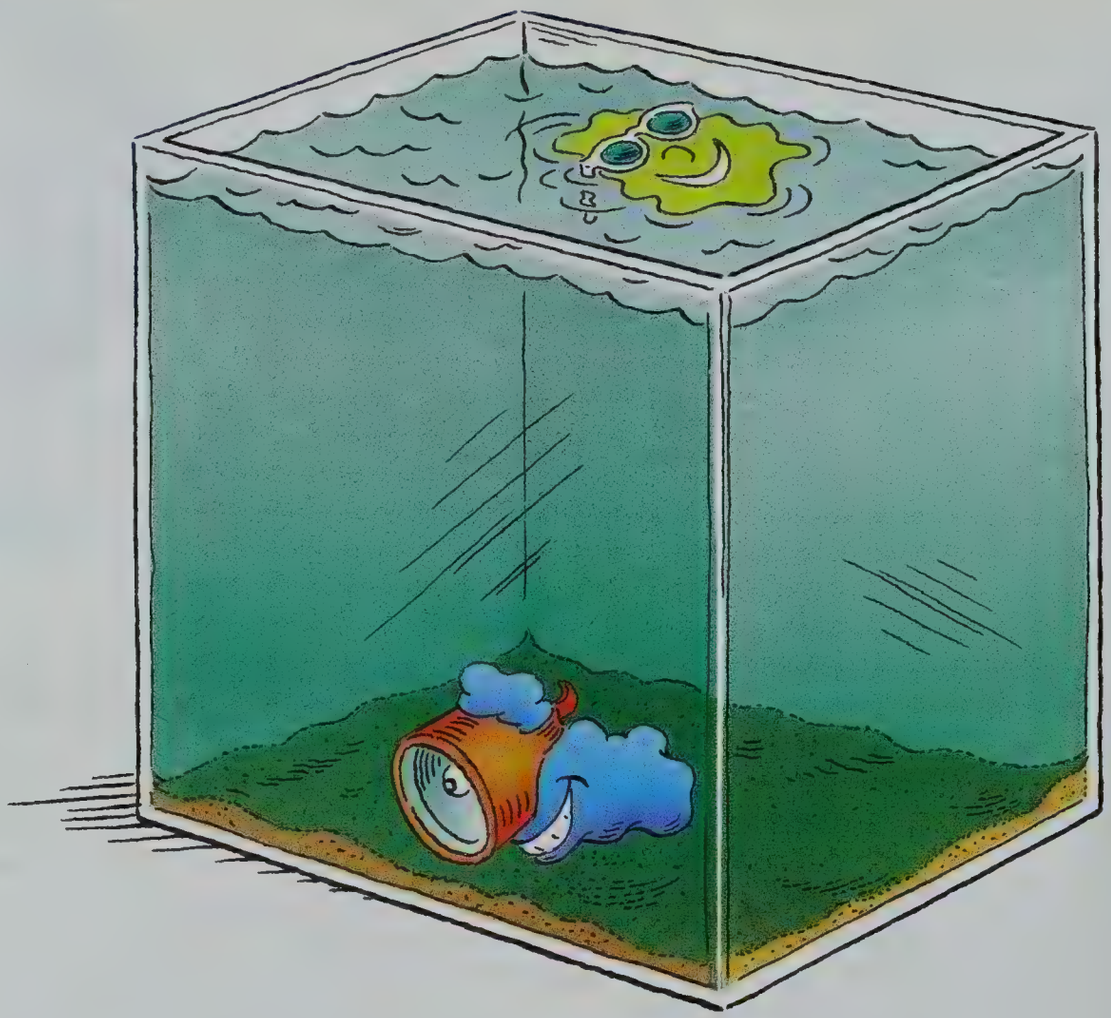
Take the cyanobacterium *Prochlorococcus marinus*. Discovered only fifteen years ago, it is the smallest and most abundant photosynthetic microbe on Earth: one tablespoon of seawater may contain 10,000 of them. Together, all species of *Prochlorococcus* make up nearly a third of the ocean biomass that uses light to make food. Penny Chisholm, of the Massachusetts Institute of Technology (MIT), points out that, along with other phytoplankton, the carbon dioxide-consuming *P. marinus* plays a key role in the regulation of CO_2 in the atmosphere. "If all the phytoplankton suddenly died," she says, "the CO_2 concentration in the atmosphere would increase two- to three-fold."

One strain of *P. marinus,* MED4, lives in rather brightly lit surface waters. Another strain, MIT9313, inhabits deeper waters. Researchers at MIT, the Joint Genome Institute in California, and the Oak Ridge National Laboratory in Tennessee have been working to determine the complete genetic instructions of both strains. And it turns out that the two are quite different.

The surface-dwelling cyanobacterium has fewer genes—1,700 compared with the 2,400 of its low-light relative. However, it possesses many more genes that are activated by light. And as befits a surface dweller, it also has an enzyme that repairs damage to its DNA caused by exposure to ultraviolet light.

What does the deepwater specialist have that its shallow-water counterpart doesn't? Apparently, it can make a living off diverse sources of nutrients. For a start, it bears genetic instructions for making enzymes capable of utilizing the nitrite that is present in deeper waters but absent from the surface waters of the open ocean. In addition, the deep-water cyanobacterium carries the codes for several enzymes that handle sugars.

Scientists are also using genomics to examine how certain microbes thrive in novel ways, using the abundant light available in the surface waters of the



SHALLOW AND DEEPWATER CYANOBACTERIA

ocean. A pigmented molecule called rhodopsin helps many creatures use light; in humans, for example, it is present in the retina. But Edward F. DeLong and Oded Beja, of the Monterey Bay Aquarium Research Institute in California, certainly didn't expect to find rhodopsin in oceanic microbes, because it had never been found in *any* bacteria. But find it they did. They confirmed that these rhodopsins are capable of harvesting biochemical energy from light, thus giving the microbes an energy boost from sunlight. Since rhodopsin-containing microbes are widespread in the sea, the researchers predict that this harvesting is an important oceanic process.

DeLong, Beja, and colleagues also discovered that microorganisms gathered from Monterey Bay and from surface waters of the Pacific Ocean north of Hawaii contain a red-reacting rhodopsin, while those from the Antarctic and the deep waters of the North Pacific have a blue-reacting variant. The difference most likely occurs because blue light reaches the farthest depths of the sea, while red light quickly attenuates with depth. The bacteria appear to have "tuned" their rhodopsins to react optimally with available light. Without modern genomics, the researchers would never have discovered oceanic rhodopsin or detected the habitat-specific spectral tuning evident in its variants.

How TB Plays Possum

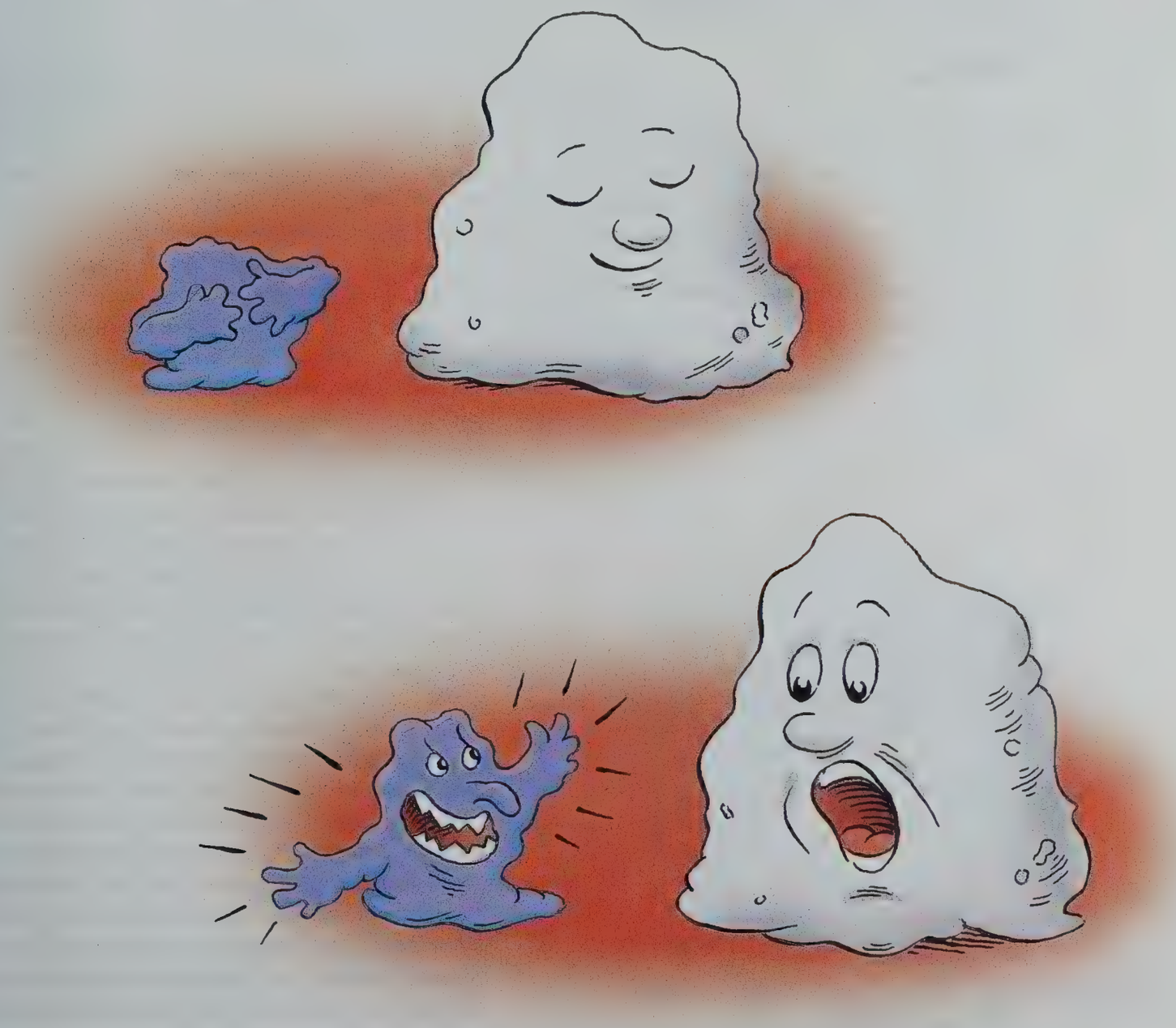
More than sixty years into the antibiotic era, tuberculosis is still the world's number-one infectious killer. One reason the disease has been so difficult to eradicate is that *Mycobacterium tuberculosis,* the microbe that causes it, has a talent for hiding out in white blood cells—sometimes for decades. A third of the world's human population harbors the bacillus in its dormant state.

M. tuberculosis may cause active disease right away, or it may weather the initial attack by the body's defenses and then enter a state of latency, persisting quietly in a kind of equilibrium with the immune system. If a host's defensive line falters (when the immune system is suppressed by AIDS, for example, or weakens with malnutrition or ad-

vancing age), active disease ensues. The ability to coexist with its host is the mark of a successfully evolved pathogen, and the tuberculosis bacterium has an extremely effective strategy for doing so, says researcher Gary K. Schoolnik, of Stanford University School of Medicine's Beckman Center.

Schoolnik has been able to show which genes the TB pathogen "turns on" when its hosts—the large white blood cells known as macrophages—start responding to its presence. When the macrophages' immune response is activated, the pathogen undergoes fundamental metabolic alterations to survive in the host cell. One component of this change is a switch to the hosts' fatty acids as a principal source of carbon for energy. The pathogen also responds to nitric oxide, one of the main products of the activated white cell. When nitric oxide levels are high, the TB pathogen seems to slow or stop replicating. When its production declines, replication resumes. The results suggest, but do not prove, that nitric oxide induces the disease's dormant state.

There are many other puzzles for Schoolnik to grapple with as he tries to unravel the secrets of *M.*



TUBERCULOSIS GERM PLAYING PEEKABOO WITH A WHITE BLOOD CELL

tuberculosis's success. For one, the microbe seems to be turning on the genes it uses to acquire iron from its surroundings, even though the nutrient mixture in which he is cultivating the microbe is rich in iron. Perhaps the toxic soup of macrophages and other white blood cells encountered by the microbe lead it to sense that iron is depleted, or perhaps more iron is needed by the bug in this environment.

So far, says Schoolnik, the lesson from the genomic investigation of tuberculosis is that what appear to be genes for ordinary metabolic functioning could in fact be crucial mediators of the infection's virulence.

Pillars of a Salty World

Sequencing the genomes of the ancient kingdom of microbes called archaea yields evidence that all life shares some basic strategies, despite disparate ways of earning a living. Consider this: the tiny genome of *Halobacterium,* a microbe that thrives in the saltiest, most landlocked bodies of water, shares many similarities with complex (eukaryotic) cells, even those from humans.

Last year, an international team finished sequencing the NRC-1 strain of *Halobacterium*. The vulture of Earth's salty puddles, NRC-1 grows on the degrading carcasses of less sturdy organisms that die off as salinity mounts due to evaporation. The genome of *Halobacterium* NRC-1 facilitates this process by including instructions for generating such exotica as a putrescine transporter—a molecular version of a waste-disposal truck. The microbe also contains the directions for making proteins that can eject toxic heavy metals such as arsenic and cadmium.

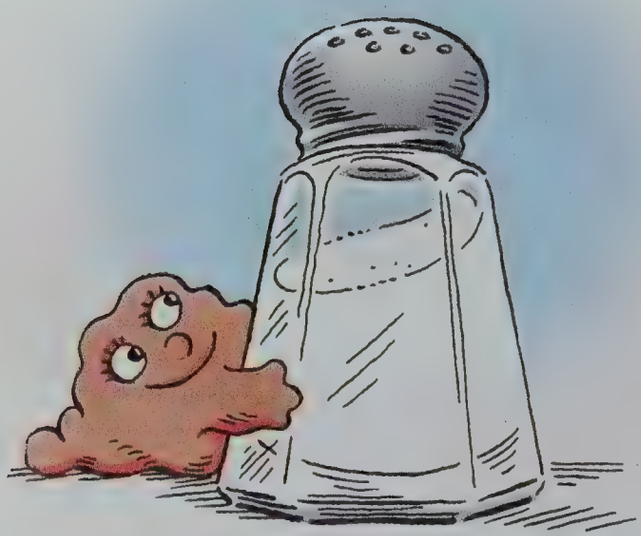
NRC-1 can prosper in water ten times saltier than Earth's oceans and can function happily with hypersalty innards. Unlike many other exotic microbes, it is easily grown in the lab, making it a potential workhorse for future research on the entire group of archaeal microorganisms known as extremophiles.

International efforts have resulted in the discovery that NRC-1 genes are carried on three replicating units, only one of which is as big as a typical chromosome; the other two are "minichromosomes." The genome sequence was used to predict about 2,600 genes, a third of which do not resemble any other known genes. Yet many of NRC-1's genes do carry instructions for familiar proteins—for example, those that facilitate molecular signaling across the cell membrane and those that are used for metabolic (housekeeping) functions. In fact, NRC-1 carries genetic instructions for making many cellular systems similar to those found in plants and animals.

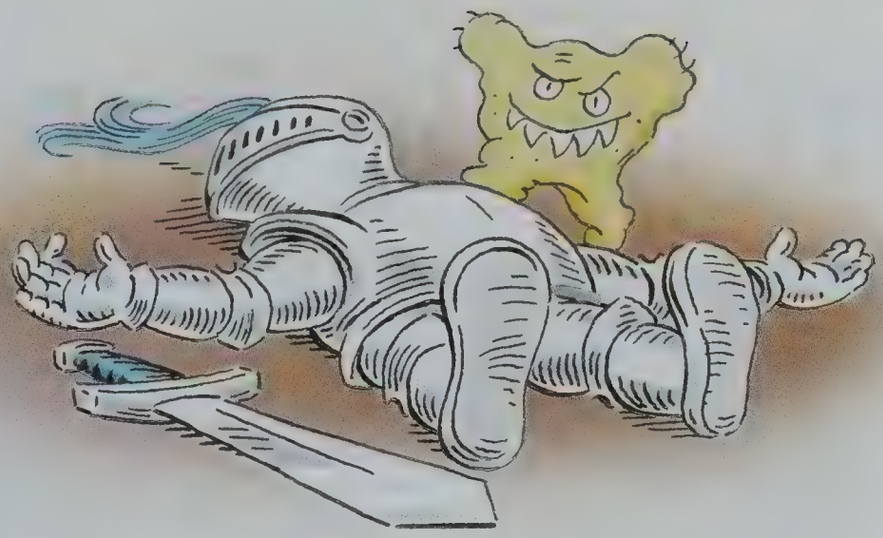
Microbiologist Shiladitya DasSarma, of the University of Massachusetts Amherst, led the international sequencing project. He explains that NRC-1's trick to surviving in ever saltier water is to have proteins on its inside that carry a high negative charge. Bacteria that lack such proteins succumb to salt poisoning.

Also found in NRC-1's genes are the machinery for growth in both the presence and absence of oxygen; a primitive photosynthesis system; and a very efficient DNA repair system that protects against damage by harsh sunlight. This hardy strain of *Halobacterium* is also genetically rigged with sensing systems that guide it to the best-lit waters and to the optimal locations where nutrients, temperature, and oxygen can stimulate its growth. NRC-1 even has a protein molecule for a membrane that can be likened to a primitive retina, and a component that in other bacteria (as well as in plants and animals) acts to maintain circadian rhythms.

All in all, the microbe should serve as an impressive genetic ambassador from its ancient kingdom.



HALOPHILIC MICROBE



TYPHUS – THE KILLER OF SOLDIERS

Typhus, Cats, and You

Despite having one of the smallest genomes known, *Rickettsia prowazekii,* the typhus-causing pathogen, has played a major infective role throughout history. More soldiers have been killed by typhus (lice spread it) than have been killed in battle. The microbe's genome itself looks like a molecular theater of war, with dead genes strewn among the living. According to Siv G. E. Andersson, of Sweden's Uppsala University, that's because fully a quarter of the microbe's compact genome is made up of a kind of junk DNA—inactivated, ancient genes in their final stages of deterioration.

Andersson, part of the team that sequenced the typhus genome, has also found that the little killer's working genes turn out to be remarkably similar to those that govern some important functions of the mitochondria, the energy-generating packets within all animal and plant cells. Mitochondria have tiny genomes that encode only a few proteins; the rest of the instructions for their task of generating cellular energy reside in the centers, or nuclei, of the cells they inhabit. The similarity between some of the nuclear genes that code for the mitochondria's energy production and the genes of the typhus organism suggests that these instructions were transferred into the nuclear genome from a bacterial ancestor of the mitochondria. According to this scenario, when oxygen levels started to rise in the atmosphere 2 billion years ago, our cellular ancestors had to adapt or die: they responded to the catastrophe by swallowing oxygen-respiring bacteria and converting them into little energy-producing organelles, the mitochondria. Andersson's sequencing of the typhus genome has yielded remarkable insights into this evolutionary heist.

When a formerly independent organism takes up residence in a host, it begins to depend on the host for its basic needs, and some of its own genetic instructions become redundant. Mutations can occur in the genes of the symbiont without consequences for its survival. Theorizing that the typhus pathogen may have had just such a history, Andersson contrasts its genome with that of *Bartonella henselae,* the microbe responsible for cat-scratch disease. Typhus microbes can survive only within other cells, whereas the cat-scratch pathogen, in the same microbial family, still carries functioning genes that allow for a more independent lifestyle. *B. henselae* microbes are taken into the infected cell, but they don't live directly in the cell's fluids. Rather, they live in a kind of bubble called a phagosome.

B. henselae can do even more for itself: it has retained genes instructing it to create the building blocks for proteins and DNA. The typhus pathogen, on the other hand, lacks the genes for making amino acids and nucleosides and depends on its host cell for a steady supply of them. As much as 80 percent of the typhus pathogen's original complement of genes may have been lost or inactivated as it evolved its completely parasitic existence, Andersson speculates.

Meanwhile, evidence accumulating from genomics suggests that the nucleus of the so-called eukaryotes, or nucleated cell organisms, is itself a donation from an ancestor of the microorganisms known as archaea. □

Born To Be Tame

To attract a mate, a male houbara bustard, above, fans his elongated crown and neck plumes and may perform an animated "display run" for an hour at a time.

To survive in the desert of Saudi Arabia, captive-bred bustards have to learn to go wild.

By Yolanda van Heezik and Philip Seddon

Imagine you're living on your own for the first time. Away from the comforts of home and in a strange town, you're preoccupied with looking for a place to get a meal and you inadvertently wander onto a dark street. A large man comes toward you. Perhaps he could give you directions. You smile hesitantly. He smiles back and then flourishes a knife. Too late, you realize you've made a fatal mistake.

In the natural world, naïveté is costly, but it is also rare in animals that share their environment with natural enemies. Constantly faced with the danger of becoming someone else's dinner, prey animals are skilled in recognizing and avoiding poten-

tial predators. In some species this ability is largely innate, while in others it seems to be learned from parents or other members of a herd or flock. Animals raised in an artificial environment and without such guidance often lack the predator-detection skills of their wild cousins.

For nine years we worked at a captive breeding center for Asiatic houbara bustards in Saudi Arabia. At the National Wildlife Research Center in Taif, female bustards are artificially inseminated and the chicks are hand-raised and then released. The goal is to reestablish healthy populations of bustards in their Saudi Arabian range. One of the first challenges the program faced was how to prepare naive bustards to survive—to eat and not be eaten—in the desert.

Camouflaged and, in their natural state, wary birds, Asiatic houbara bustards are at home in the undulating steppes and semideserts of the Arabian Peninsula, western and central Asia, and the Indian subcontinent. Superbly adapted to arid environments, wild houbaras do not need to drink water but manage to get all the moisture they need from their food. Indeed, part of the secret of the bustards' survival may be their varied diet. Opportunists at heart, they will try most edible objects they encounter, from juicy berries and young green shoots to crunchy beetles and sunbathing lizards. Though powerful fliers, houbaras prefer to walk and are more difficult to discern when on the ground. When they do take to the air, their size (wingspread is about five feet), their deep wingbeats, and the black patches on their wings and neck make them easy to recognize. Houbaras' strong flight, coupled with a fighting spirit, make them a premier quarry in the ancient sport of falconry. This kind of hunting, in which the falcons are trained to attack much larger birds, is one reason bustards are threatened throughout much of their range.

Houbara bustards are also sensitive to human disturbance. Before Saudi Arabia's oil-fired economic expansion, the wanderings of nomadic herdsmen were dictated by the presence of water and green vegetation. Today water is trucked to livestock, and both the herds and the four-wheel-drive vehicles penetrate once pristine landscapes. In response to the decline of resident houbaras in the Arabian Peninsula, the Saudi government began a conservation program in 1986. This project included captive breeding and the creation of large protected areas. By 1992 the successful program of artificial insemination and incubation had produced a surplus of chicks, enough to begin introducing some of them into the wild. Juvenile birds, from thirty-five to forty-five days old, were at first released into a predator-free enclosure of about one and a half square miles, where they could learn how to find natural food. In their own good time, the young birds could simply fly out into the wider reserve, a fenced area of 850 square miles that was free of livestock and human predators but had a full complement of natural predators. Some bustards, on first leaving the enclosure, immediately retreated back inside, while others headed off into the desert.

XAVIER EICHAKER; NWRC PHOTO LIBRARY

Tiny and mainly insectivorous, Rüppell's fox, above, rarely preys on newly released bustards, but many of the young birds fell victim to red foxes.

Considering the enormous transition the young birds had to make, many of them fared well as far as food finding was concerned. After growing up on a diet of unlimited food pellets, alfalfa, mealworms, crickets, and water, they were somehow able to rec-

XAVIER EICHAKER; NWRC PHOTO LIBRARY

YOLANDA VAN HEEZIK

Houbara bustard chicks, above, are cared for by hand. Right: A young red fox, Sophie, was enlisted to give predator-avoidance lessons.

ognize and collect their natural plant and insect foods. They coped without water in temperatures that soared above 100° F and eventually even figured out how to breed successfully.

The main stumbling block along the road to self-sufficiency was predation. As more and more of the newly free young birds fell victim to deadly attacks, we considered a list of likely suspects. The delicate little Rüppell's fox inhabits the region, but its predominantly insectivorous diet and small size argued against its being the villain. (However, should a hungry Rüppell's fox blunder upon a recently released bustard barely able to fly and searching for its water dish, then the fox is likely to prefer

YOLANDA VAN HEEZIK

Eager to chase bustards, Sophie is kept in hand by author Philip Seddon. Each carefully supervised training bout lasted just three minutes.

the bird over another beetle.) The lovely, wide-faced sand cat could have preyed on some birds, but the habits of this desert species are little known. Later on, we found that eagle owls could become habitual houbara killers once they discovered how easy it was to dispatch naive birds. But our investigation of the tracks and other signs around predator-killed carcasses indicated that the main culprit was the red fox.

Not as common in the region as Rüppell's foxes, red foxes ordinarily pose little problem for houbara bustards. Wild houbara chicks, usually two or three per clutch, stay with their mother for about three months in total, even though they begin to fly short distances at one month of age. They are taught by their mothers or other bustards how to recognize and avoid foxes and other dangers. The captive-bred houbaras missed out on these lessons, and many paid the price. Navigating a new, seemingly limitless environment, finding appropriate sources of food, and learning to live without water was demanding, yet possible. Having to cope with predators at the same time was too much.

To help get the birds through this critical period, the research center's staff decided to trap foxes living around the predator-free enclosure and move them far away. When the young birds left the enclosure, provided they remained close by, their chances of running into a hungry fox were diminished. Despite these trapping efforts, more than half the bustards released were quickly killed by predators—three-quarters of these by red foxes. Removal of foxes from a buffer zone around the enclosure had only delayed the birds' encounters with predators; the proportion killed was the same.

Our bustards were in danger of becoming "bird nerds"—hand-reared individuals that, if they manage to survive, still have handicaps that even other

XAVIER EISCHAKER; NWRC PHOTO LIBRARY

Although primarily ground birds, houbara bustards are strong fliers when they take to the air, right. In the wild, clutches—usually of two or three eggs—are laid directly on the desert surface, below.

NWRC PHOTO LIBRARY

members of their own species can readily recognize. A study of captive-bred male partridges, for example, has shown that when released, these birds not only lacked some basic survival skills but also were less attractive to females than were wild birds. Hand-reared female partridges were more likely than their wild counterparts to lose their eggs and chicks to predators.

Could our birds be instructed how to recognize predators and behave appropriately around them? At first, we tried exposing the naive birds to simulated attacks, using a stuffed red fox. This method was safe and allowed us to repeat the training trials. But while the young bustards did seem to fear the model, when released they were just as likely to be devoured by a fox as were unschooled birds. We began to think that the birds would benefit by experiencing a more realistic attack. For this we needed a live predator, but we wanted one we had some control over. To this end, one chilly March morning, we raided a fox den in northern Saudi Arabia, carefully extricating a ten-day-old female fox.

We named her Sophie. She spent her first weeks snuggled inside layers of our clothing and waking us up at night with her warbling wails for food. As she grew, her prowess at chewing and climbing was marked by our gradually raising all our possessions onto higher and higher shelves and into cupboards far from fox-reach. Sophie was very playful and liked nothing better than to be entertained by us. Her delightful personality threatened to shift our allegiance from bustards to foxes. We reminded Sophie that she was going to have to work for her keep, and we spent time trying to accustom her to walking on a lead and wearing a muzzle. We failed miserably on both counts. The lead was sometimes ignored, and at other times Sophie went off at a breakneck pace, dragging us behind, until she jerked to a halt to investigate some odoriferous burrow or bone. The muzzle was apparently a grievous insult to a fox and resulted in her complete immobility. We despaired that she would ever be of use in training the bustards.

The day came, however, when young birds were ready to be moved from the captive breeding facility to the enclosure, and Sophie was caught, collared, and taken to a specially designed training cage. The birds had three training sessions, of about three minutes' duration each, over the course of a week. During those three minutes Sophie would tear around the cage, darting both at and away from

the bustards, sending them up and crashing into the cloth walls and roof in a panic. We were treading a fine line between making the sessions frightening enough to teach the birds the lesson and damaging them. Eventually, half the bustards were "trained"; the other half, a control group, did not make Sophie's acquaintance.

Before being released, all the birds were fitted with radio transmitters that allowed daily monitoring of their movements. We then waited anxiously for news. Past experience had told us that most deaths would occur within about two weeks after the birds left the security of the enclosure. As expected, over the next few weeks, some birds went missing and some were lost due to illness or injury. Even if a bird was killed by a predator, its transmitter usually remained intact. The remains of individuals could be found quickly, and a cause of death could usually be ascribed. Within a few months, we were able to congratulate Sophie on the contribution she had made to houbara bustard conservation. Her foxiness must have left a lasting impression on the young houbaras, because significantly more birds in the "trained" group survived.

Most of the bustards that fell prey to foxes did so during the first week on their own. None of those that died survived longer than nineteen days, but those that lasted more than nineteen days appeared to be no longer at risk. We believe this is the critical period during which the bustards learn to adapt to a new diet and new environment.

The houbara bustards' experience with Sophie may have helped them develop some simple rules—the primary one being to react rather than hesitate during a dangerous encounter. Our training technique is now available for use as future releases take place in new sites. We like to think we took a little of the nerd out of the birds and gave them a flying start toward self-sufficiency and a real life in the Arabian Peninsula. □

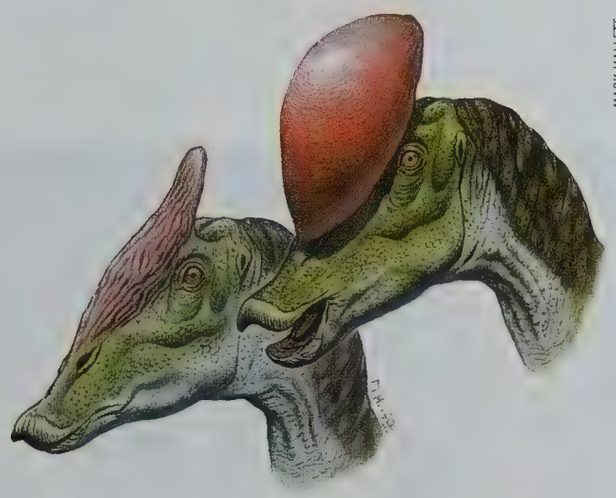
Stillness and cryptic coloration can be natural defenses in the bustard's environment. Below: A captive-bred female bustard, equipped with a radio transmitter, is almost invisible as she incubates her eggs.

The big, bulbous nose of the adult male proboscis monkey consists of erectile tissue that fills with blood when he is excited. This causes the nose to become red and swollen—a display that speaks volumes to the female, whose own nose is petite and upturned.

A NOSE FOR ALL REASONS

From courtship to camouflage, sinking to swimming, there's a nose for the job.

By Lawrence M. Witmer



MARK HALLETT

From the size and arrangement of fossil nose bones, paleontologists are certain that many dinosaurs had huge, fleshy noses. The anatomy of some, such as the hadrosaur *Saurolophus*, left, suggests the presence of inflatable nasal sacs. One way to explore this and other possibilities is to study the noses of living animals—the hooded seal, for example.

Noses are for more than just smelling—or for holding up spectacles, as Pangloss remarks in Voltaire's *Candide*. Olfaction is certainly the nose's ancestral role, and smelling remains important for most animals, but in many disparate groups of vertebrates the organ has been co-opted for a variety of other, quite different functions. The reasons for the nose's evolutionary adaptability are straightforward. For starters, it is well positioned to greet the environment. In addition, it can be modified without compromising essential tasks such as locomotion or chewing. Finally, nasal anatomy makes use of diverse raw materials—bone, cartilage, muscle, blood vessels, connective tissues—on which natural selection can draw.

I was thrust into the arena of nose anatomy by dinosaurs. Along with Scott Sampson, of the University of Utah, I had noticed that certain groups of dinosaurs had enormous and complicated noses, some taking up half the skull. Clearly, something biologically important was going on. Previous researchers had proposed a number of possibilities, based on loose analogies with animals living today. Hoping to unravel the enigma of dinosaur noses, we decided to conduct our own studies of modern analogues. My collaborators (including many students) and I soon discovered just how evolutionarily labile the vertebrate nasal apparatus is.

A variety of mammals, such as tapirs and elephants, have evolved a trunk (nose plus upper lip) capable of manipulating objects. In many species, the nose has been transformed into a display organ, such as the fleshy knob on the snout of the gharial, the inflatable sac of the hooded seal, and the swollen nasal appendage of the proboscis monkey. Often—as in these three species—only the males possess display-worthy noses, which serve to communicate information about their health and status both to females and to rival males. Many birds and some antelopes, notably the dik-dik and the saiga, sport noses that give them an exceptional ability to regulate brain temperature and conserve water.

The list could go on—the nasal snorkel of many aquatic turtles, the nasal leaf of many echolocating bats—but the general point is that all these noses are built from a limited set of anatomical tissues. Evolution "makes do" with what's available. Now our task is to add all this information to the fossil evidence, with the goal of reconstructing the dinosaurs' soft tissues and determining the biological roles of their nasal novelties. Our studies of tapirs, for example, indicate that dinosaurs most likely did not have trunks, as some researchers have proposed. Instead, we think that the nose of *Triceratops* and some other enormous dinosaurs was not a mechanical tool, and we are currently homing in on its precise physiological function. Stay tuned.

MICHAEL AND PATRICIA FOGDEN

The enigmatic nasal appendage of Madagascar's leaf-nosed snake may enhance camouflage and/or improve the animal's sense of touch. The male's nose ends in a tapering spike and the female's in a flattened "leaf," so the appendage may play a role in social display as well.

MICHAEL AND PATRICIA FOGDEN

The nose of the white bat is shaped like a leaf, an adaptation for echolocation. Leaf-nosed bats vocalize through their noses, not their mouths, and the leaf both modulates and focuses the sound.

ART WOLFE; PHOTO RESEARCHERS, INC.

MITSUAKI IWAGO; MINDEN PICTURES

A tapir's trunk works more like an octopus's tentacle than like a typical vertebrate appendage. Made mostly of muscle, fat, and connective tissue, this highly flexible organ is useful for everything from rummaging in debris on the forest floor to "directional smelling."

DOUG ALLAN; BBC NATURAL HISTORY UNIT

Male hooded seals have two dramatic displays. The first (inset) involves closing both nostrils and exhaling, thus inflating the highly elastic black skin of the nose. For the second display, the male closes just one nostril and exhales, blowing out the blood-red elastic nasal septum through the other nostril.

ART WOLFE

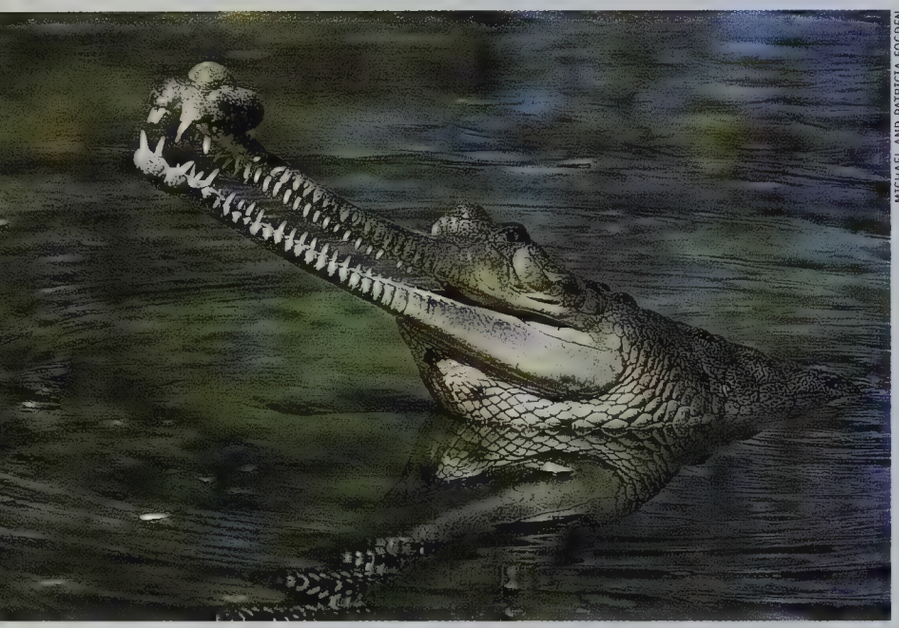
In their hot, arid African habitat, dik-diks may go months without drinking. The anatomy of the proboscis and nasal cavity enables these tiny antelopes to reclaim water otherwise lost during exhalation and to cool blood going to the brain.

JOE MCDONALD; ANIMALS ANIMALS

In many soft-shelled turtles, the nasal cartilages are greatly elongated, effectively turning the nose into a snorkel. Thus equipped, the turtle can remain submerged, periodically extending its nose above the water's surface to breathe.

MICHAEL QUINTON; MINDEN PICTURES

Moose noses are expanded affairs, with cartilaginous plates and connective tissue pads that make the muzzle both tall and broad and that widely separate the nostrils. Thick nasal pads help seal off the nostrils when the moose submerges to feed on underwater plants.



MICHAEL AND PATRICIA FOGDEN

The snout of the male gharial is graced by a stiff, hollow knob, used in both visual and acoustic displays. Building a nose ornament entailed the evolution of a new means of closing the nostrils: penislike erectile tissue that, when engorged, seals off the airway.

FRANS LANTING; MINDEN PICTURES

Once thought to be airspeed indicators, the nostrils of the southern giant petrel and some other ocean birds help in the excretion of excess salt. Salty fluids drain from glands above the eye, pass through the nostril (a long, horny tube perched atop the beak), and ultimately drip off the bill tip.

FRANS LANTING; MINDEN PICTURES

Formed by thousands upon thousands of small muscles that confer both strength and versatility, the elephant's trunk is perhaps the most remarkable multipurpose vertebrate appendage. It is used for breathing, sniffing, manipulating objects as small as a single blade of grass, lifting an entire tree trunk, taking a shower or dust bath, and snorkeling across a river. In short, it does everything one could ask of a nose —and then some.

IN THE FIELD

Tundra fire in northwestern Alaska

DANIEL GULLICKSON; BUREAU OF LAND MANAGEMENT

Arctic Fires

Tundra flowers wait for lightning to strike.

By Peter J. Marchand

For eons, wildfire has played a fundamental role in the evolution of plant traits. Around the world—in grasslands, coniferous forests, chaparral—fire influences the makeup of plant communities, shapes the way many plants grow and reproduce, and regulates the course of natural succession (the orderly replacement of one group of species by another over time). Fire may even play a major role in determining what types of flowers bloom in the cold arctic tundra.

My first experience with tundra fire came in Alaska's Noatak River watershed, where sparse stands of white spruce give way to a seemingly endless expanse of dwarf shrubs and tussock-forming sedges that stretch northward to the farthest horizon. Although the soils in this region are usually cold and wet (permanently frozen ground known as permafrost lies only inches below the surface), plant matter that has accumulated over many seasons often dries out in early summer and becomes vulnerable, for a brief period, to wildfires triggered by lightning strikes. And the impact of fire here can be far longer lasting than might be expected for a landscape dominated by low-growing shrubs and herbs.

Flying over the confluence of the Noatak and Kugururok Rivers, where ecologist Charles Racine has established a research site for the study of tundra fires, I could see the extent of a 30,000-acre burn that had once charred the area. Its boundaries were clearly delineated by the fresh green of vigorous new growth, standing out sharply against a charcoal gray backdrop. At the site, Racine and his assistant Kathy Hutchins were monitoring changes in the plant community, quantifying what I had already suspected: the fire had set into motion a complex cycle of events, giving some species all the advantage they needed to gain a foothold. Already, several new colonists—among them bluejoint grass, fireweed, fourpart dwarf gentian, horsetail, and arctic saxifrage—had invaded the site. It would be many years before the tundra could return to its pre-burn state.

In a place where permafrost is a feature of the environment, the makeup of the plant community depends largely on the depth to which the soil thaws each summer. The depth of the thaw is determined by a tenuous balance between heat lost during the dark winter months and heat gained during the perpetual days of summer. This balance, in turn, depends greatly on the nature of the ground cover, since this is what absorbs or reflects sunlight and insulates the soil. Adding wildfire to the equation may shift the balance dramatically. A newly fire-blackened surface substantially increases absorption of sunlight, and in the absence of insulating plant cover, the absorbed heat is efficiently conducted downward. By season's end, the depth of thaw in burned areas may be 50 percent greater than in unburned tundra. And it doesn't take plants long to respond. Sedges sprout vigorously, spurred by a flush of nutrients resulting from the accelerated activity of soil microorganisms as well as from the burning of dead plant matter. Other species, unnoticed at the site at the time of the burn, suddenly show up; some are carried in from afar, and some germinate from seed lying dormant in the soil. Even cotton grass, a widespread and dominant tundra species that reproduces year after year by cloning, profits from fire. Its dense, knee-high tussocks are built up through the prolific sprouting of belowground stems, but fire stimulates flowering and seed production, introducing fresh genetic material into a stand and keeping the species adaptable.

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The plants that benefit most from wildfire, though, may well be arctic annuals. Annual species (those that must germinate from seed, grow to maturity, and produce a new crop of seed within a single season) are something of a novelty in this environment, where the likelihood of their success is greatly diminished by compression of the growing season into forty or fifty days. Removal of the established plant cover and exposure of the soil, however, bring out the best in these fast-growing opportunists. Kneeling among a blue profusion of gentian blossoms, Hutchins measured the response of this annual to the fire, counting more than 200 plants and 1,200 flowers per square yard where the soil was blackened and competing vegetation had been destroyed. While she found that the total number of plants at the study site differed little from the number at unburned sites, one flower characteristic stood out: seed maturation at the study site occurred fully one week earlier than it did in plants from unburned areas. For arctic annuals racing to finish seed production before the first killing frost, this was as good as a three-length lead in the homestretch of the Preakness. Testing the seeds back in the lab, Hutchins found them to be 87 percent viable—as good as any commercial seed grower could hope for. The annuals in burned areas were clearly getting a jump start.

When tundra vegetation remains free from fires and other disruptions, the long-lived sedges form large clumps that are often drier than the surrounding soil and eventually become colonized by lichens, mosses, willow shrubs, and alders. These invaders slowly crowd out their predecessors, changing the environment by shading the ground, which reduces soil temperature and makes it even more difficult for annuals to become established. But fire, if only occasional (it occurs once every three to four years somewhere in the Noatak River valley), reverses this course of succession just often enough to keep annuals in the game. Like fire-adapted pines, which bank seed for future generations in tightly closed and long-lasting cones, the resourceful arctic annuals invest their future in an underground seed bank. We now know that every square yard of tundra soil holds many hundreds of seeds of diverse species. Biding their time in this cold-storage depository, the seeds await some change to tip the balance of competition in their favor. And in this frozen Eden, there's nothing like a good fire to rouse them from dormancy and spark a summer bloom.

Peter J. Marchand is currently a visiting scientist at the Carnegie Museum of Natural History's Powdermill Biological Station in the Allegheny Mountains of western Pennsylvania.

Saxifrage in the Alaskan interior

CHARLIE OTT; NATIONAL AUDUBON SOCIETY/ PHOTO RESEARCHERS, INC.

Charred spruce forest near the Koyukuk River

FRED HIRSCHMANN

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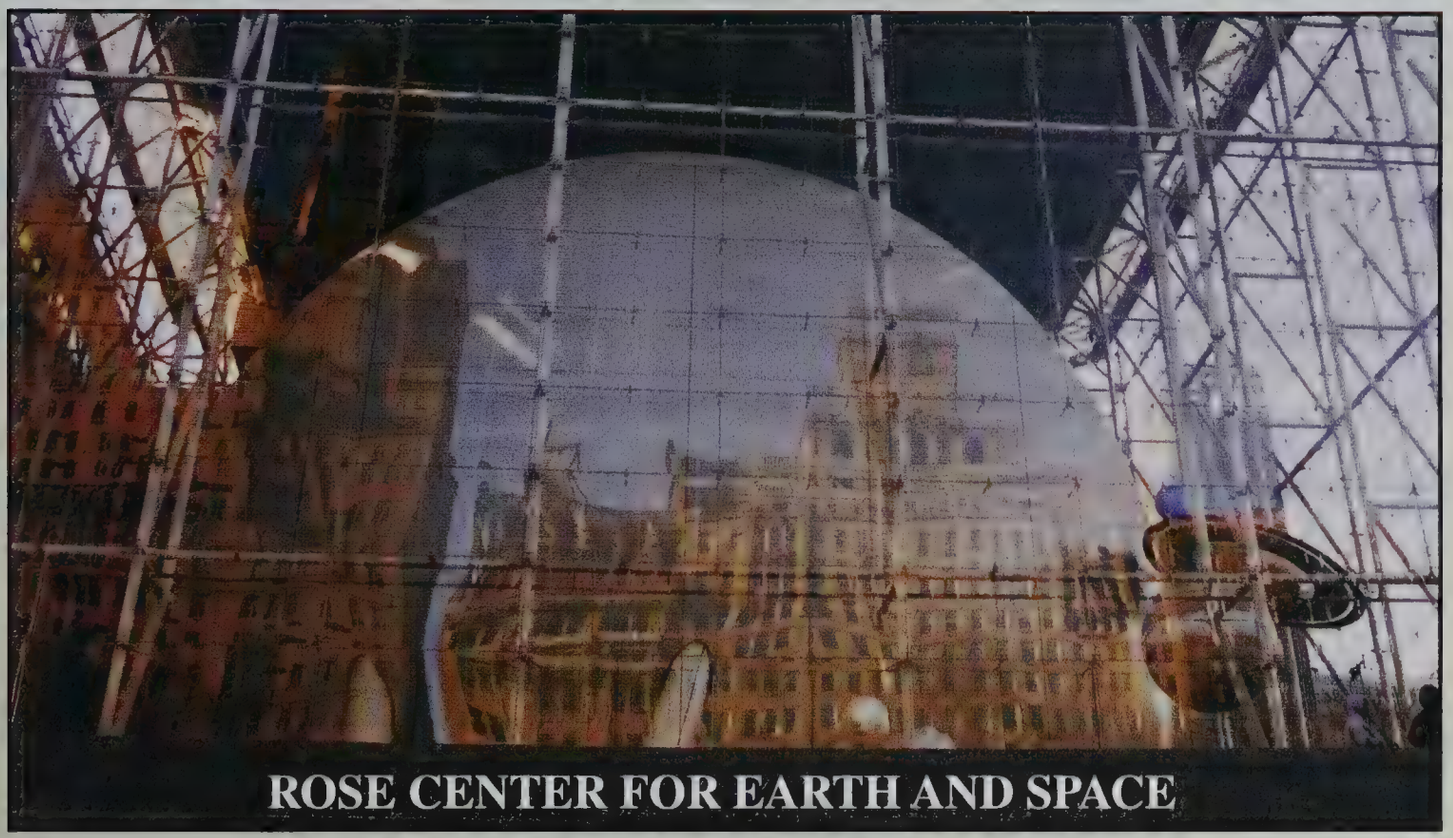

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REVIEW

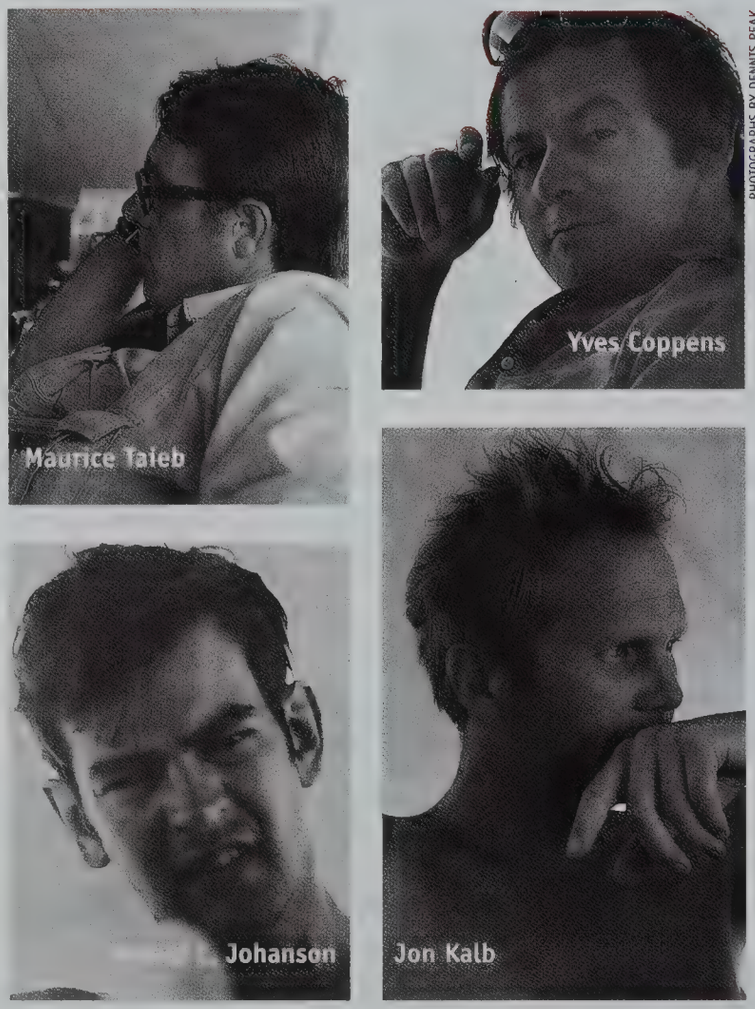
Hardball Among the Hominids

Fossil riches in the Horn of Africa have sparked decades of cutthroat competition.

By John Van Couvering

History, they say, is written by the winners. If so, we may have been missing some good books. Jon Kalb's engrossing account of discovery and disappointment in the Afar region of Ethiopia may be one of the best first-person accounts of finding human fossils ever written. In 1971, as a restless and somewhat overmature graduate student in geology, Kalb—galvanized by the fossil-finding successes of well-financed French, American, and Kenyan groups working near the northern tip of Lake Turkana—decided to move his family to Ethiopia and put together his own expedition into the last unexplored segment of the East African Rift System. Alas, once the hominid remains began to turn up, Kalb was the first (but not the only) loser in the appalling academic brawl that ensued, even as Ethiopia was exploding in waves of murderous revolution. Threaded through this vivid story of fieldwork, paleoanthropological politics, and on-the-spot war reportage is Kalb's nervy struggle simply to stay in the game.

In these pages we are backstage for some of the great scenes in human paleontology, a long-running saga of triumphs and jealousies that might have been written by Giuseppe Verdi. Nearly fifty years had passed since Raymond Dart astounded the world with the discovery of the Taung skull in southern Africa, giving anthropologists a new human ancestor to fight over. In the 1970s in South African caves and East African rift valleys, especially Kenya's Turkana basin, discoveries and hard feelings were reaching a crescendo. At first, Kalb and his partner, French geologist Maurice Taieb, had the infernal landscape of Ethiopia's Afar Depression to themselves. It was a jagged wasteland of ovenlike heat, frantic mosquitoes, and unfordable, unsanitary rivers, with a local population that had a history of wiping out exploration parties. Describing how he and Taieb learned to get around in this terrible place (and how they began to find fossil beds wherever they looked), Kalb uses such vivid and compelling imagery that one wishes—almost—to have joined them there.



PHOTOGRAPHS BY DENNIS PEAK

The prevailing mood at the Afar field camp in 1973

Some needed no urging. Not long after news that the Afar had fossil beds dating back millions of years reached the who's who of hominid paleontology that was entrenched around Lake Turkana, Kalb and Taieb were sought out by a young professor, Yves Coppens, representing the French presence in the area, as well as by an ambitious graduate student, Donald C. Johanson from the U.S. team. Louis Leakey, who had been sidelined by illness and politics after organizing the Kenyan contingent, was also eager to know more about the Afar fossils.

When Leakey and his wife, Mary, met Kalb at a congress of prehistorians at Addis Ababa in December 1971, Mary Leakey stressed the importance of Kalb's not trusting anybody when it came to hominid fossils. As it turned out, she couldn't have been more prescient. From that time onward, the action in Kalb's story quickens inexorably as it dawns on everyone that the Afar is the biggest, the most fossiliferous, and (surely) the most newsworthy of all the fabled locales in human evolution. The Afar Depression, however inaccessible a hellhole, appeared to be the one re-

maining place on earth that had geological potential for a paleoanthropological bonanza. (As Kalb notes, however, there's always the Sudan.)

Various accounts exist of what happened, but the central facts are the same in all of them: In late 1972 Kalb and Taieb signed an agreement to cooperate with their French and American partners and were jointly awarded a permit by the Ethiopian government's Antiquities Administration to study the geology and paleontology of nearly 13,000 square miles of the Afar's Awash River valley. In October 1973 Johanson came across hominid remains—australopithecine leg bones—as the team was exploring at Hadar (in the northern part of the concession). Just eleven months later, Kalb was forced out. Kalb claims that the reason given by the director of the Antiquities Administration was that a rumor of his connection with the CIA had been brought to their attention by Johanson. Within months, his former partners Taieb and Johanson announced the discoveries of "Lucy" and of the 2.3-million-year-old "First Family," a cache of 214 fossil bones and teeth of early hominids of both sexes and different ages found in a single locality.

Adventures in the Bone Trade: The Race to Discover Human Ancestors in Ethiopia's Afar Depression, *by Jon Kalb (Copernicus Books, 2001; $29)*

Kalb, meanwhile, managed to retain a corner of the original concession—in the Middle Awash valley, where nobody had yet explored. He assembled another team, and sure enough, in May 1975, they found a vast trove of Acheulean hand axes and cleavers, "the artifacts so dense in places that they [could] be seen from an airplane at 2,000 feet." In October 1976, in the same place, they found the 600,000-year-old Bodo cranium.

Three proposals for work in the Middle Awash went to the National Science Foundation (NSF) in 1977 from Kalb's eminently qualified associates at Southern Methodist University, New York University, and Harvard—and all three were rejected. The following year, Kalb was expelled from Ethiopia on six days' notice. The bitterest part of the book is Kalb's dry description of how the area of the Middle Awash was then taken over by J. Desmond Clark and his associates from the University of California, Berkeley, who had previously obtained an overlapping permit.

Denied funds to investigate the Bodo site further, Kalb went to the NSF to see if his supposed CIA involvement was the problem. He was blandly informed that the rejections were strictly on merit—that no such rumor had ever reached their ears. In 1986 Kalb filed a lawsuit against the NSF under the Freedom of Information Act and won a court-stipulated settlement as well as a public apology from the NSF. Their records showed that the CIA rumor was indeed a factor. The information released to Kalb showed that Clark, who moved into the Middle Awash only weeks after Kalb was out of the way, was one of the referees who had argued privately to reject the Harvard application due to the CIA rumor (the other two applications had vanished from the files).

Now a research fellow at the University of Texas at Austin, Kalb paints an engaging and sympathetic picture of himself as a good guy who got steamrollered. Skull digging without skullduggery is hard to imagine, however, and Kalb may just not have been as proficient a hardball player as his competitors. I recall the wry diagnosis of "the hominid game" offered by a paleontologist who was in Kenya studying fossil fish at the time. "It's always a bad combination," she concluded, "when you get hominid fever on top of testosterone poisoning."

John Van Couvering is a geologist and the editor and publisher of the Museum's Micropaleontology Press.

nature.net

Biology's Giant Leap

By Robert Anderson

The preliminary map of the human genome is complete, but as the scientists who worked on the project readily admit, the hard work is just beginning. Researchers will be trying to figure out the role that each gene plays in our complex biochemistry. Even with only 30,000 genes—far fewer than the original estimates—this task could take decades.

For wide-ranging information about the Human Genome Project, try the site at www.ornl.gov/hgmis/. Also, the "Human Genome Special" of the British weekly popular-science magazine *New Scientist* has nice online summaries of what biology's big moment means for all of us (www.newscientist.com/news/genome.jsp).

For budding student geneticists who want to get in on the action, I recommend starting with the University of Utah's Genetic Science Learning Center site (gslc.genetics.utah.edu). Its "Basic Genetics" section has a primer on how our cells translate DNA's genetic information into the multitude of proteins our bodies need. Science becomes personal in the "Genetic Disorders" section, in which young people suffering from a rare genetic disease, neurofibromatosis, share their experiences. For news about how genetic research is changing the world, click on "Genetics in Society." Or try the "Students" section, with demonstrations such as "How to extract DNA from anything living": Place split peas (or onions or chicken liver) in a blender; add water and salt; blend; then add a little detergent, meat tenderizer, and alcohol, in sequence. *Et voilà,* you get strands of sticky DNA, the code of life. Seeing is believing.

Robert Anderson is a freelance science writer living in Los Angeles.

PHOTOGRAPHY

Primal Forces, *photographs by David Muench and Marc Muench; text by Michelle A. Gilders (Graphic Arts Center Publishing, 2000; $50)*

BOOKSHELF

Brave New Brain: Conquering Mental Illness in the Era of the Genome, *by Nancy C. Andreasen (Oxford University Press, 2001; $29.95)*

Neuroimaging of the thalamus reveals that it is smaller in schizophrenics. According to Andreasen, a neuroscientist, future mapping of the organ holds the promise of finding in "this small haystack . . . the quixotic needle that can be used to slay one of the biggest giants of mental illness."

The Misunderstood Gene, *by Michel Morange (Harvard University Press, 2001; $24.95)*

"Organisms are algorithms that are incarnated in DNA molecules and in proteins." So writes this French biologist, intent on looking at genes as synthesizers of proteins and on offering precise accounts of how they operate in such fundamental life processes as development, aging, learning, and behavior.

The Impact of the Gene: From Mendel's Peas to Designer Babies, *by Colin Tudge (Hill and Wang/Farrar, Straus and Giroux, 2001; $27)*

For Tudge, a scientist turned writer, the immense possibilities of biotechnology raise the disturbing question, Is our basic humanity at risk?

Transducing the Genome: Information, Anarchy, and Revolution in the Biomedical Sciences, *by Gary Zweiger (McGraw Hill, 2001; $24.95)*

Storing and analyzing the genomic data of our species, writes Zweiger, promises to create "a dramatically new understanding of life" but also to impose on us the enormous responsibility of becoming "stewards of our own genome."

Cracking the Genome: Inside the Race to Unlock Human DNA, *by Kevin Davies (The Free Press, 2001; $25)*

Davies, the founding editor of *Nature Genetics,* gives a lively account of the costly and intensely competitive effort to decipher the full genetic composition of human beings. The Human Genome Project, begun in 1990 and completed this year, "represents an extraordinary technological achievement, and is at best perhaps the defining moment in the evolution of mankind."

Abraham Lincoln's DNA and Other Adventures in Genetics, *by Philip R. Reilly (Cold Spring Harbor Laboratory Press, 2000; $25)*

Doctor, geneticist, and lawyer Reilly examines the diverse uses of genetic technologies, from the proposal to diagnose a disorder in Lincoln's DNA known as Marfan syndrome to using animal organs in humans.

Perspectives on Genetics: Anecdotal, Historical, and Critical Commentaries, 1987–1998, *edited by James*

F. Crow and William F. Dove (University of Wisconsin Press, 2000; $19.95)
This collection of essays originally appeared in *Genetics.* Written by such contributors to the field as Joshua Lederberg, Richard C. Lewontin, and John Tyler Bonner, they richly document the history of modern genetics research and its continuing evolution.

Decoding Darkness: The Search for the Genetic Causes of Alzheimer's Disease, *by Rudolph E. Tanzi and Ann B. Parson (Perseus Publishing, 2000; $26)*
Isolating the genes and proteins responsible for this neuron-wasting disorder (now affecting 20 percent of people age seventy-five to eighty-four and 40 percent of those eighty-five and over) has been Tanzi's quest since the early 1980s.

The Seven Daughters of Eve: The Science That Reveals Our Genetic Ancestry, *by Bryan Sykes (W. W. Norton, 2001; $25.95)*
Modern genetics permits us to journey into the deep past of our species, "way beyond the reach of written records or stone inscriptions," writes geneticist Sykes. "These genes tell a story which begins over a hundred thousand years ago and whose latest chapters are hidden within the cells of every one of us."

The Way of the Cell: Molecules, Organisms, and the Order of Life, *by Franklin M. Harold (Oxford University Press, 2001; $27.50)*
In 1944 physicist Erwin Schrödinger published his book *What Is Life?* This ageless question is at the heart of Harold's investigation of the ubiquitous "process of living" and the unique capacity of organisms "to reproduce themselves indefinitely, and arise on a millennial time-scale by the interplay of variation and selection that underlies biological evolution."

The books mentioned are usually available in the Museum Shop or via the Museum's Web site, www.amnh.org.

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MUSEUM EVENTS

EXHIBITION DEPARTMENT; AMNH

June 9: Opening of the Discovery Room, an interactive space for families with children ages five and up. Activities are available in all the Museum's major fields of science and research, from anthropology to astrophysics. Tuesday–Sunday, 10:00 A.M.–5:00 P.M.; Friday 10:00 A.M.–8:45 P.M.

JUNE 4

Lecture: "What's the Matter in the Universe?" (Frontiers in Astrophysics series). Astronomer Vera Rubin. 7:30 P.M., Space Theater, Hayden Planetarium.

Lecture: "Dragon Hunter: The Life of Explorer Roy Chapman Andrews." Writer and archaeologist Charles Gallenkamp. 7:00 P.M., Kaufmann Theater. For more information, call (212) 313-7607.

JUNE 5, 12, AND 19

Three lectures: "Evolution and Genomics," Rob DeSalle, curator of the exhibition "The Genomic Revolution," June 5; "Natural History of the Genome: The Role of Genes in Nature, Extinction, Mutations, and Status," Niles Eldredge, curator, Division of Paleontology, June 12; and "Genetic Diversity and Native American/First Nations Cultural Issues," Linda Burhansstipanov, executive director, Native American Cancer Research Corporation, June 19 (Science of the Genome series). 7:00 P.M., Kaufmann Theater.

JUNE 6, 9, 13, 20, AND 27

Films and discussions in connection with "The Genomic Revolution": *The Lost Tribes of Israel* (DNA research aids a quest for identity), June 6, 6:30 P.M.; *Gene Hunters* (genetic research and indigenous peoples), June 9, 2:00 P.M.; panel discussion on art and biotechnology, June 13, 7:00 P.M.; *Amrit Beeja* (traditional agriculture and agribusiness in India), June 20, 6:30 P.M.; *After Darwin* (possibilities and ethics of genetic technologies), June 27, 6:30 P.M. Kaufmann Theater (except June 13, Linder Theater). For additional screenings on May 26 and 30, call (212) 769-5200.

JUNE 7

Lecture: "Transition From Sail to Steam: Archaeology and the Social History of Ships" (Earthwatch at the Museum series). Anthropologist Richard Gould. 7:00 P.M., Kaufmann Theater.

DURING JUNE

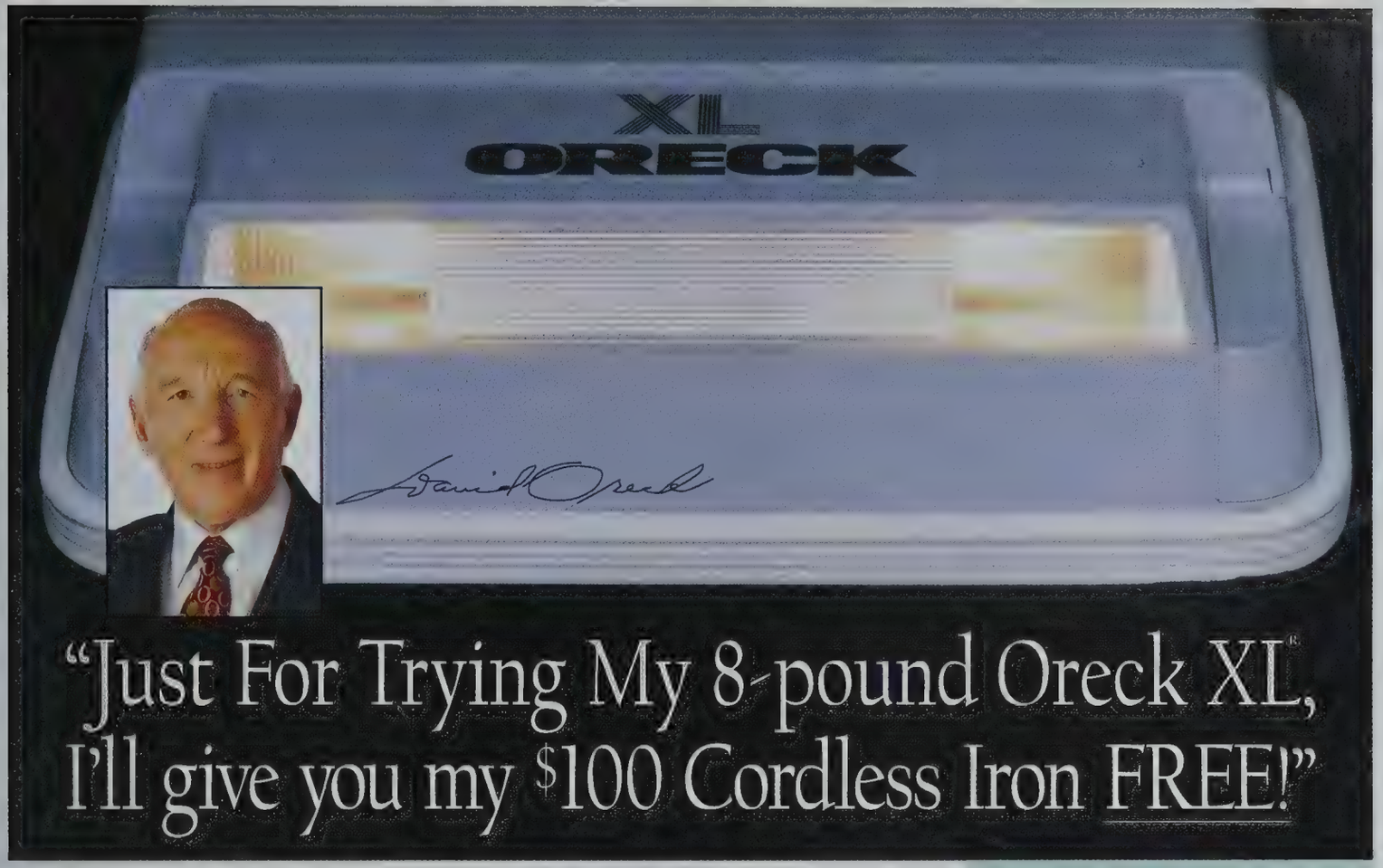
A fossil of a subadult theropod (125–145 million years old) discovered in northeastern China is on display in the Astor Turret. This dinosaur, covered with well-preserved featherlike structures, probably looked much like a bird.

For information on field trips and workshops for adults and children, inside and outside the Museum, call (212) 769-5315.

Seminars on Science: Six-week online courses for K–12 teachers on subjects including genetics, spiders, fishes, and life in the universe. Continuing education and graduate credits available. For more information, visit www.amnh.org/learn/pd/sos/.

Films at the IMAX Theater: *Lost Worlds: Life in the Balance* (biodiversity and the need for conservation); *Shackleton's Antarctic Adventure* (the dramatic story of the 1914–17 British Imperial Trans-Antarctic Expedition); and *Ocean Oasis* (the biodiversity of the Baja California peninsula).

The American Museum of Natural History is located at Central Park West and 79th Street in New York City. For listings of events, exhibitions, and hours, call (212) 769-5100 or visit the Museum's Web site at www.amnh.org. Space Show tickets, retail products, and Museum memberships are also available online.



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THE NATURAL MOMENT

Woodworks

Photographs by **Jim Brandenburg** Minden Pictures

Charles Darwin admired the special adaptations of woodpeckers, citing their stiff tail spines, hard-pointed bills, and shock-absorbent necks. While most of these birds are small and forage by drilling holes in tree bark to extract one grub at a time, the crow-sized pileated woodpecker *(Dryocopus pileatus)* hacks away at wood on a somewhat larger scale—both to excavate nests for its young and to expose whole colonies of ants. During February and March, a male and female may pound on a dead branch or old tree trunk for as long as a month to excavate a nesting cavity in which to raise three or four chicks. Both parents take turns incubating the eggs and bringing food to the chicks. Males sit on the eggs mainly at night. The parent feeding a chick in the photograph (inset) was spotted in a mixed conifer-hardwood forest in northern Michigan, near the Canadian border.

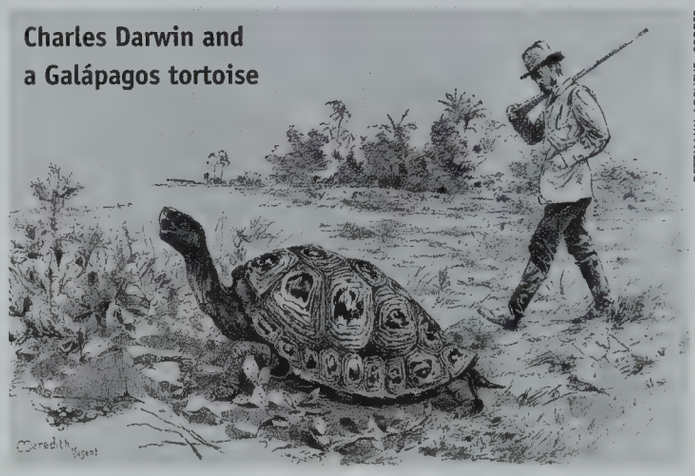
Although their diet includes some acorns and beechnuts in the fall, pileated woodpeckers eat mostly ants, flying insects, grubs, and some seeds and fruits. Carpenter ants are a special favorite. When the forest floor is blanketed in snow, the birds use their powerful bills to dig out ant nests from tree trunks and tree bases. Jabbing at the wood, they remove chips three to six inches long. According to some observers, these woodpeckers feed on the sap that runs from the trees' wounds and also eat the insects that are lured by the flow of sugary liquid.

Woodpeckers of this species have been known to rescue endangered eggs. In one documented instance, when a dead tree containing a nesting cavity collapsed, the female retrieved each of her three eggs with her bill and flew them to a hollow in another tree. On his return to the original nesting site two hours later, the male began a frantic search of the area and finally managed to locate his family. The pair soon settled in their new home and resumed their breeding efforts.—*Richard Milner*

ENDPAPER

Would Darwin Get a Grant Today?

By T. V. Rajan



Charles Darwin and a Galápagos tortoise

BETTMANN ARCHIVE; CORBIS

For the first half of the twentieth century, biological research was dominated by scientists who studied whole organisms in their natural settings. In recent decades, this approach to the study of life has increasingly been perceived as a poor cousin to molecular biology and has even, in some scientific circles, been contemptuously dismissed as stamp collecting. The change began as several forces conspired to bring about a reductionist approach. One powerful influence was the 1944 publication of a book entitled *What Is Life?* by Austrian physicist Erwin Schrödinger, whose work was vital to the development of quantum mechanics. In this book, Schrödinger maintained that physics could help explain why genetic traits are so stable—why, for example, a particular malformation of the lips (known as the Hapsburg lip) turned up over several centuries in members of the German royal family.

Physicists who felt that quantum mechanics had exhausted the possibilities offered by inanimate objects were inspired by Schrödinger's words to turn their attention to biology. These scientists brought with them the bias that studying individual molecules was the only plausible approach to understanding systems as complex as living organisms. This approach produced a massive explosion in our understanding of the molecular basis of life, teaching us that organisms derive their enormous complexity from a vast number of relatively simple interactive systems. Unfortunately, I feel, the molecular biology revolution has put the baby at risk of being thrown out with the bathwater.

I am often involved in reviewing grant proposals in my own field—biomedical research—and over the years have witnessed a disturbing trend. Nearly all the worthy molecular studies receive the funding they need, while many promising clinical projects—following the progression of a disease in real human patients, for instance—are turned down. This is regrettable, because both approaches are critical to understanding the many complex factors involved in any disease: the genes that may predispose someone to a particular illness, the environmental or other triggers that may bring on the illness, and the numerous factors (some, but not all of them, genetic) that determine how the illness progresses.

Some scientists believe that genetic information will soon render clinical or descriptive research moot. I am skeptical. The precise amino-acid substitution in the hemoglobin of patients with sickle-cell anemia has been known for approximately forty years; so far, however, this knowledge has done little to help manage the disease. The inevitable time lag between a genetic discovery and any alleviation of human suffering that might result from the discovery should be grounds enough to dictate steady financial support of clinical as well as molecular studies.

Furthermore, nature is notoriously frugal with her resources. Most genes play multiple, often little-understood roles in an organism. Altering a gene in order to treat one condition may leave the patient vulnerable to other problems. For example, the early onset of puberty in girls is associated with health risks, including an increase in the chance of developing breast cancer, so why not try to inhibit premature menarche? The enzyme responsible for breaking down the male hormone testosterone (which females also have, though in lesser amounts) may cause premature menarche. Wouldn't it make sense to tinker with the enzyme in order to increase a girl's testosterone level? No, because tinkering with it would adversely affect other areas of her physiology, such as her susceptibility to cardiovascular disease.

My concerns are not limited to medicine. I fear we may be discouraging many young people—the possible intellectual descendants of Darwin—who might otherwise choose to study organisms in the wild. In my view, this is tragic. As much as molecular biology and genomics can teach us, to deeply understand living organisms requires that we also study how their physiology is structured, how they evolved, and how they function in their current ecological settings.

Fortunately, as readers of *Natural History* know, field biology is far from dead, and many field biologists are now incorporating molecular biology into their research programs. As we begin to appreciate the limits of reductionism, I am optimistic that descriptive biology will come back into fashion and once again be recognized as an essential part of our efforts to understand life.

T. V. Rajan is chairman of the pathology department at the University of Connecticut Health Center in Farmington.

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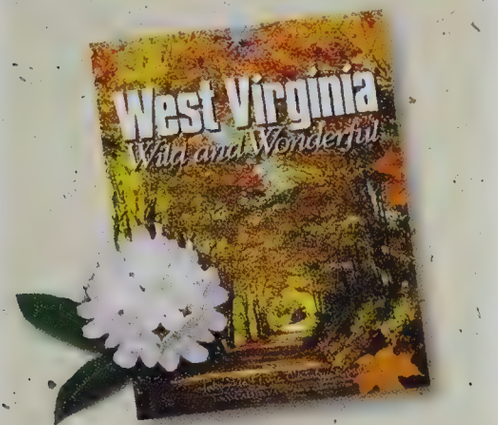

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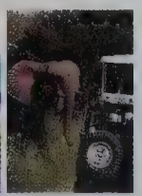

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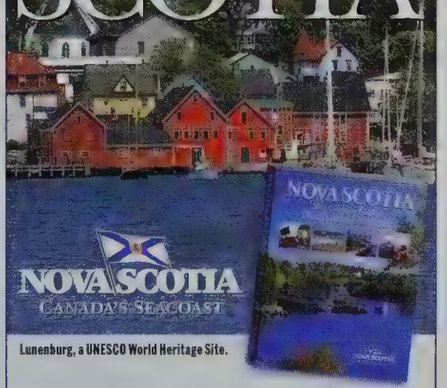

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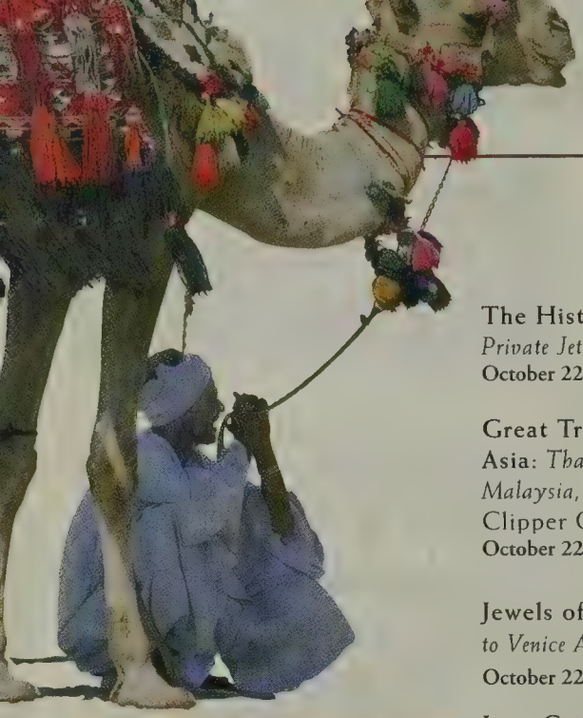

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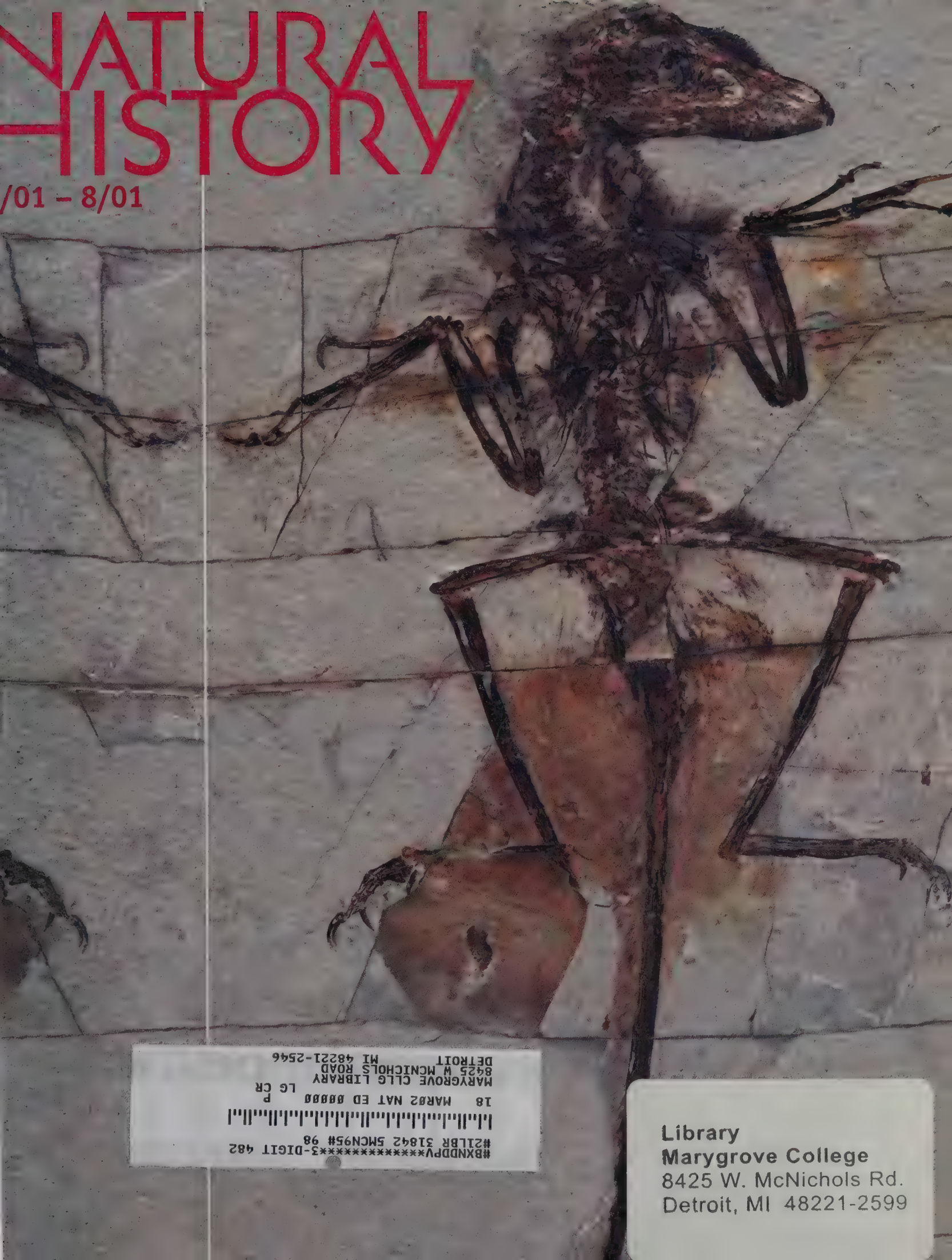

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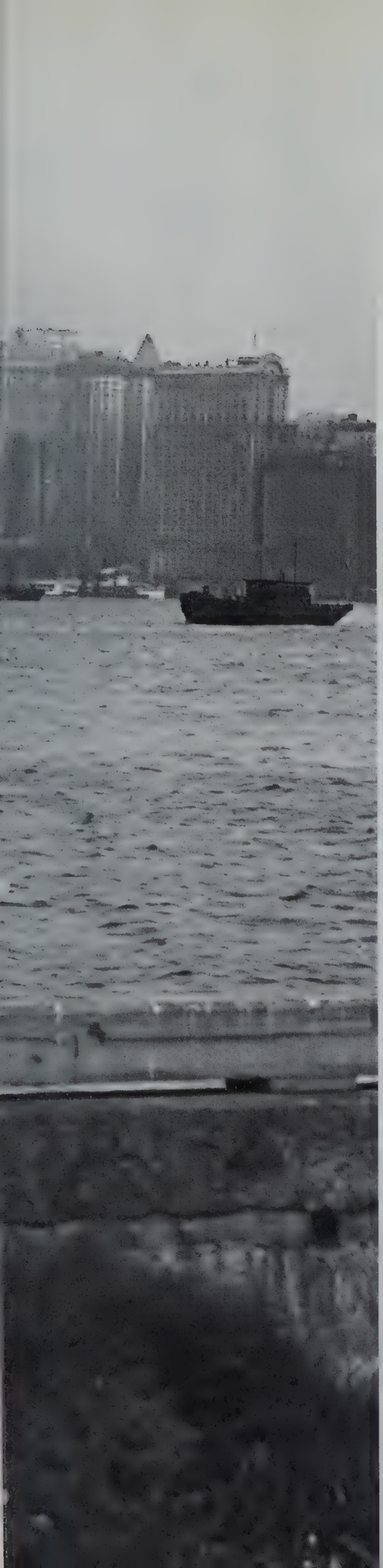

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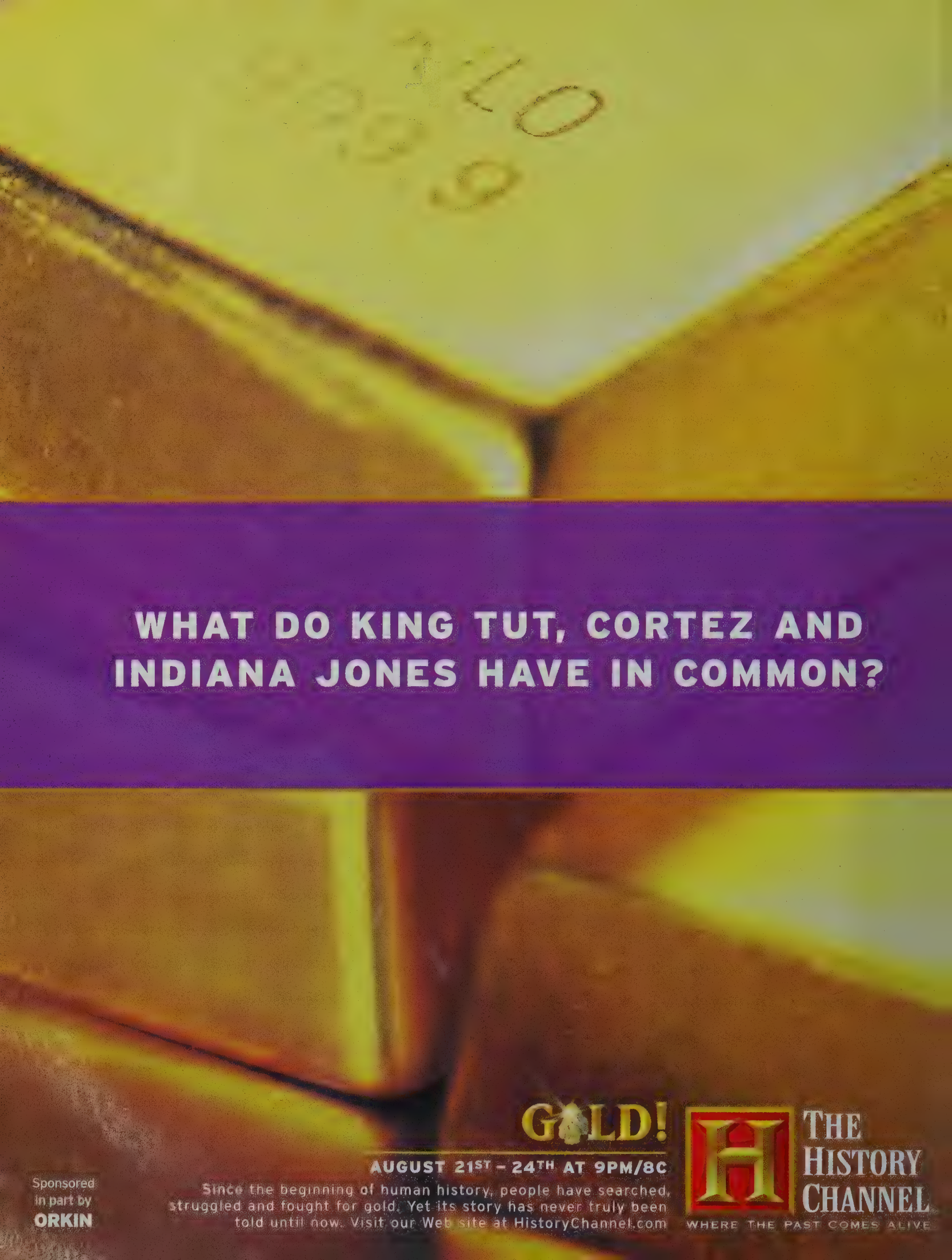
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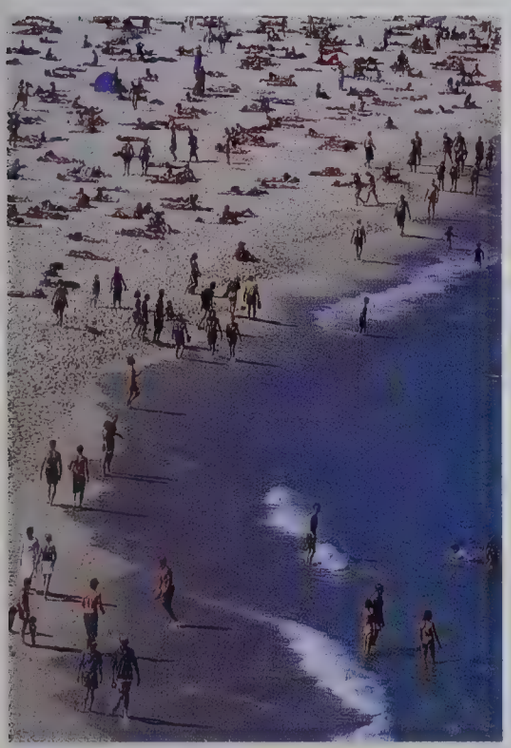

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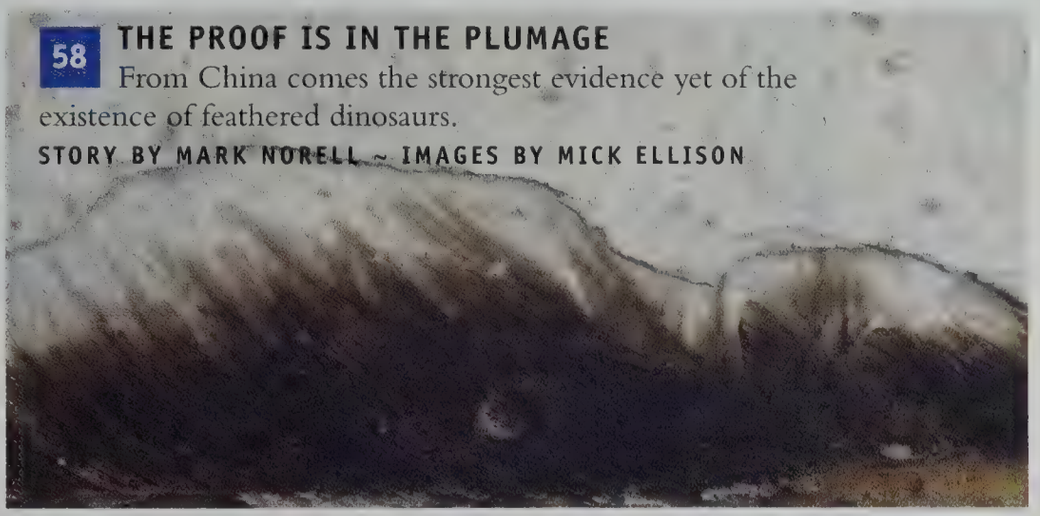

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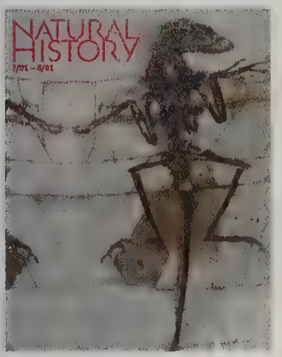

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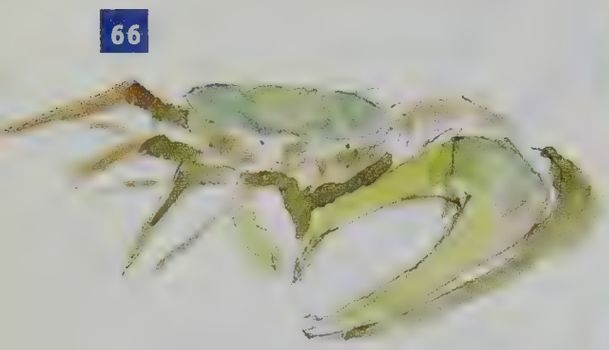

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UP FRONT

The Dark Side of the Sun

At some point in the recent history of our species, people of European descent began to cultivate the suntanned look. (Notions of physical beauty are often tied to symbols of prosperity and leisure. A suntan—which once signaled long hours of working outdoors—became in the twentieth century a conspicuous advertisement that one had nothing more pressing to do than travel to a seacoast and lie about on a beach blanket.)

Biologically, suntans—and dark-pigmented skin in general—tell another, more objective story: that human beings have an ambivalent evolutionary relationship with the sun. Yes, our star is the source of all life and energy, yet we can never look straight at it, and overexposure to its radiation can be fatal. Other animals, as well as plants and protists and bacteria, have the same paradoxical involvement with the sun. That's why hammerhead sharks get suntans, why some sea urchins eat algae, and why certain grasses produce chemical sunscreens.

J. GURMAN, S. PLUNKETT, S. HILL, S. HAUGAN; SOHO/NASA

Ultraviolet image of an explosion on the sun

Back in 1985, the British Antarctic Survey announced that the ozone layer was thinning and that living things were being exposed to elevated levels of ultraviolet radiation—the form of sunlight with the greatest potential to cause biological harm. Getting a suntan, like cigarette smoking several decades earlier, dropped from the list of life's harmless pleasures.

Science writer Jay Withgott ("Feeling the Burn," page 38) reports on biological research that has followed the discovery of the ozone hole, relaying the sometimes reassuring, sometimes alarming findings. If you happen to read this article while vacationing at the beach, please move into the shade.—*Ellen Goldensohn*

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LETTERS

Theories of Relativity

Regarding Jared Diamond's interesting article "Deaths of Languages" ("Nature's Infinite Book," 4/01): the Crimean word *marzus* (wedding) sounds Turkic to me. And indeed, a phrase for "wedding" in modern Turkish is *evlenme merasimi,* in which *merasim* carries the sense of "ceremony." You might find a cognate for *marzus* in old Tatar tongues.
Bill Shepherd
via e-mail

Might Crimean Gothic's *marzus* have had a Latin origin? I suggest the following cognates: Old French *mariage* (marriage); Latin *maritare* (to marry), from Latin *maritus* (husband); and English "marriage."
Kenneth L. Sanders
Fort Myers, Florida

The word *marzus* is recognizably related to the Indo-European origins of "marriage": Latin *maritus* (husband); Sanskrit *maryas* (lover); Lithuanian *marti* (bride); Welsh *merch* (girl); even French *mari* (husband).
Eric W. Knight
New York, New York

JARED DIAMOND REPLIES: Quite a few correspondents wrote to suggest that the Crimean Gothic word *marzus* might somehow be related to our English word "marriage," which entered English from French and ultimately from Latin *maritare* (to marry). This suggestion turns out to illustrate a fascinating general problem in linguistics.

While some linguists also derive *marzus* from *maritare,* others doubt the words are related, for two reasons. First, although both the Crimean and the Latin word share the syllable *mar-,* it's hard to trace the other syllable, *-zus,* to a Latin root. Hence some linguists have suggested similar-sounding Lithuanian, Greek, and even Arabic words as antecedents of *marzus.* Second, most recognizable Crimean Gothic words are Germanic, with a smattering of loan words from the languages of other people with whom the Goths had contact, particularly the Iranians, the Turks, and the Greeks. Little or no evidence exists for Latin influence on Crimean Gothic, making one wonder whether the resemblance of *marzus* and *maritare* is accidental. If one compares the vocabularies of undoubtedly unrelated languages—Navajo and Basque, for example—one can still find similarities of sounds in about 15 percent of all corresponding words, because human speech consists of only a finite number of sounds. This problem of distinguishing chance similarities from real relationships is the most difficult single problem for linguists trying to detect relationships between languages that might, at best, be only distantly related.

Mothers and Udders

Sarah Blaffer Hrdy ("Mothers and Others," 5/01) made no mention of a common baby-sitting custom here in Texas cattle country. One mother cow baby-sits a group of twelve to fifteen calves whose mothers are out grazing, usually nearby. Coyotes, and in some areas dog packs, would find easy pickings if it were not for the guarding cow. Every hour or so a grazer comes back, finds her own calf and nurses it, then lies down and relieves the caretaker, which gets up and goes out to graze. All the mothers take their turns, but the lower-status cows seem to have less free time and much more baby-sitting duty.
Elizabeth S. Roach
Eliasville, Texas

Expanding Space

In his informative article "Cosmic Plasma" ("Universe," 5/01), Neil deGrasse Tyson states that a few microseconds after the big bang, the size of the universe "was not much larger than our solar system." For that to be the case, the speed of expansion would have to have been several orders of magnitude greater than the speed of light, which would have violated the principles of relativity. Is there something I'm missing?
Ivan Stanko
via e-mail

NEIL deGRASSE TYSON REPLIES: Let there be no doubt, the speed of light is not just a good idea, it's the law. But this law applies only to objects that move through a preexisting space, not to the expansion of space itself. So the universe can expand as fast as it wishes, carrying the galaxies along for the ride at less than, the same speed as, or faster than the speed of light.

The Truth About Seahorses

I've been studying the pygmy seahorse *Hippocampus bargibanti* for several years and have spent more than 180 hours underwater observing them, in collaboration with Amanda Vincent and Project Seahorse. I wish to clarify some statements that appeared in "Coral Stables" ("The Natural Moment," (4/01). At present it is an assumption that the male broods the young as in other seahorses. We hope to have a definite answer later this year. Furthermore, I have witnessed a pygmy seahorse birth in which not just a few but thirty-four juveniles were released from one adult. The gestation period is less than the several weeks implied in the short article, and these seahorses' monogamy may be short-lived. Presently we do not know what pygmy seahorses feed on. We still have much to learn about these delightful creatures.
Denise Nielsen Tackett
Paden City, West Virginia

Natural History's e-mail address is nhmag@amnh.org.

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CONTRIBUTORS

A former electrical engineer, **Kathryn Rusch** ("Whispers in the Canyon," page 32) was working on a sound-transmission study in southeastern Arizona when she became fascinated by the hummingbirds fighting and vocalizing at a feeder in Ramsey Canyon. This led to her long-term studies of the songs of blue-throated hummingbirds and other canyon denizens. Rusch, seen here with her younger daughter, Michaela, is a research assistant at the University of Wisconsin-Milwaukee Field Station in Saukville. Her two daughters, now ages seven and four, help her with research on ruby-throated hummingbirds in their backyard.

Science writer **Jay Withgott** ("Feeling the Burn," page 38), whose story examines the biological impact of ultraviolet radiation, recently published an article in *California Wild* on whether microbes could survive UV exposure in outer space, as well as a piece in *BioScience* on the role of ultraviolet light in the vision of birds and other animals. Withgott has done graduate research on snake predation and on aphids and is an avid birder. He also accompanies his wife, Susan Masta, a biologist, in collecting toads and spiders. "She hopes that after doing this article, maybe I'll remember to use sunscreen," he says.

Butterfly specialist **Phil Schappert** ("Butterfly Buffet," page 46) is a lecturer at the University of Texas at Austin's School of Biological Sciences and manager of its Stengl "Lost Pines" Biological Station. About sixteen years ago, in Ontario's Lake Superior Provincial Park, Schappert chanced upon an unforgettable sight: hundreds of colorful nymphalid butterflies blanketing a black bear carcass. Later, he began to wonder why butterflies feed "on the most unappealing substances imaginable." Schappert has authored *A World for Butterflies: Their Lives, Behavior and Future* (Firefly Books, 2000).

While looking for an Andean topic for his master's thesis in ethnology, **André Affentranger** ("The Condor and the Bull," page 50) learned about the traditional condor bullfight in Cotabambas, Peru, and reasoned that there must be a significant interplay between the event itself and the attention lavished on it by the media. A native of Switzerland, Affentranger (left) is completing his doctoral thesis at the University of Basel and editing a video about the condor bullfights. Born in Italy, **Ernesto Bazan** is a travel and news photographer based in Havana. He was the photographer for two previous stories in *Natural History:* "The Season of *Las Parrandas*" (December 1997/ January 1998) and "Cuba's All-Stars" (April 1999).

Curator and chairman of the American Museum of Natural History's Division of Paleontology, **Mark Norell** ("The Proof Is in the Plumage," page 58) has been at the forefront of documenting the evolutionary relationship of theropod dinosaurs and birds. In Mongolia, he discovered the first embryo of a carnivorous dinosaur, the theropod *Shuvuuia*, and the strange Mongolian bird *Mononykus* (see "New Limb on the Avian Family Tree," September 1993). Norell (right) has also analyzed the new fossil birds and dinosaurs emerging from northeastern China. Illustrator and photographer **Mick Ellison**, who has visited the Chinese site five times, is principal artist in the Museum's Division of Paleontology. In addition to his work illustrating fossil creatures, he enjoys painting portraits of people.

After completing a master's thesis in geology, German-born **Theo Allofs** ("The Natural Moment," page 80) changed direction and launched a career in travel photography. A few years later, he decided to become a full-time nature photographer; his subjects have included orangutans in Borneo, capybaras in Brazil, and flying foxes in Australia. He and his wife, Sabine, live in a log home near Kluane National Park in Canada's Yukon Territory. To see more of Allof's award-winning work, visit www.theoallofs.com.

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THIS LAND

Following the Silver Trail

Vestiges of mining towns line a route into the central Yukon.

By Robert H. Mohlenbrock

Canada's northwesternmost territory, the Yukon, has just two major highways—the Alaska Highway, which runs east to west across the southern part of the region, and the Klondike Highway, which starts south of Whitehorse (the territory's capital) and runs northwest through Stewart Crossing to Dawson City. The great Klondike gold rush, which followed the discovery of gold along Bonanza Creek in 1896, was responsible for making Dawson City a major town. Stewart Crossing is near Stewart Creek and Duncan Creek, where gold was discovered in 1895 and 1889, respectively. Silver-rich deposits of galena, a lead ore, were mined in an area northeast of Stewart Crossing. The road leading there, which strings together the three towns of Mayo, Elsa, and Keno City, is still known as the Silver Trail.

One cool August morning, my wife, Beverly, and I got an early start out of Whitehorse and followed the Klondike Highway for 120 miles, to the few buildings that remain of Stewart Crossing. We then turned onto the Silver Trail, which at first follows the Stewart River upstream. After about two miles, our view of the river was obscured by a white spruce forest. The forest grows atop permafrost, a layer of soil that remains frozen year-round. A dense ground cover of mosses provides insulation

during the summer, helping to preserve the permafrost below.

Another ten miles or so down the road, the landscape broadened into a floodplain, and twenty miles farther along, we saw a pair of low ridges. These are moraines—glacial deposits of sand and boulders—marking the western limit of glacial ice in the Stewart River Valley some 14,000 years ago, during the most recent ice age. East of here, geologist Christopher Burn has reported, the area was once covered by ice up to 1,500 feet thick.

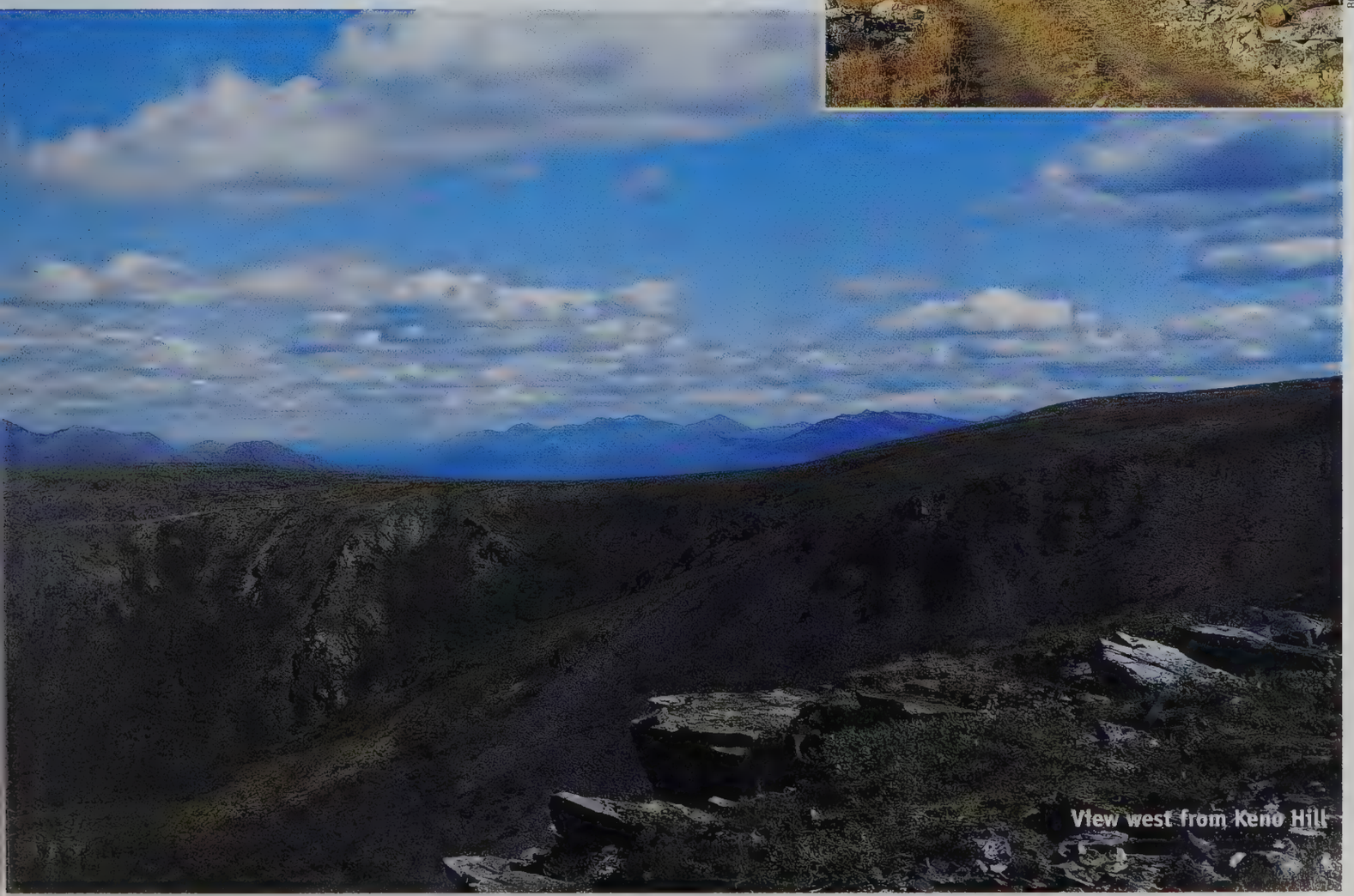
Just outside Mayo, thirty-six miles along the Silver Trail—about the halfway point—we reached a bed-and-breakfast where we had arranged to spend two nights. Mayo, which once boasted 30,000 inhabitants, now has about 500. Nevertheless, it is the region's center of activity. (Elsa is nearly a ghost town, with less than half a dozen residents, while Keno City has about twenty-five.) Coincidentally, Mayo holds the record for both the coldest and the hottest temperatures in the Yukon. In February 1949, a low of –80° F was recorded, while in June 1967, the temperature rose to 97° F.

After we had spent the night, the host of our bed-and-breakfast drove us to Keno City. On the way, near the former settlement of Minto Bridge, we stopped to see a "drunken" forest of spruce trees tilted at various angles. The forest owes its appearance to an adjacent lake, one of a number of thermokarst lakes in the region. Such lakes originate from the melting of ice in the upper layer of permafrost; in this case, according to Burn, the melting resulted from nineteenth-century forest fires. Because the lake does not freeze to the bottom in winter, deeper layers of permafrost beneath it, as well as the frozen soil around it, continue to thaw. As the banks of the lake collapse, the trees begin to topple.

The trip to Keno City gave me the opportunity to see Keno Hill, which rises several hundred feet above the

Miner's cabin

BOTH PHOTOGRAPHS BY RICHARD HARTMIER


View west from Keno Hill

town. Reaching 6,755 feet above sea level, the top of the hill is above the timberline, and several plants unusual for this part of Canada grow here. A rough road leads up to the summit, passing first through one of the northernmost stands of alpine fir in the world. On the way up, we stopped to examine the roadside vegetation in this forest and again, above the timberline, to see a wet meadow and a dry meadow. Finally we reached the rocky summit, which harbors tiny flowering plants. In most of these species, the leaves are crowded into a compact "cushion" that protects them from the harsh, drying winds.

Robert H. Mohlenbrock, professor emeritus of plant biology at Southern Illinois University, Carbondale, explores the biological and geological highlights of U.S. national forests and other parklands.

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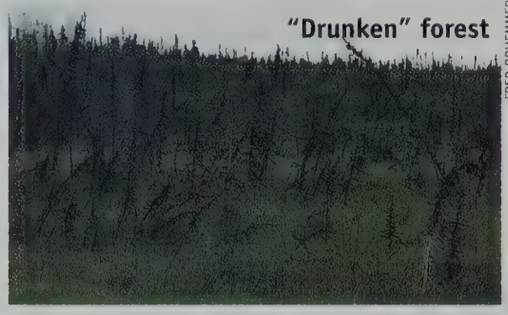
JOE LEMONNIER

HABITATS

White spruce forest also includes paper birch and balsam poplar. The shrub layer has western rose, buffaloberry, northern comandra, and shrubby cinquefoil, while the ground is carpeted with both soft mosses and crunchy reindeer moss (actually a lichen). Canada goldenrod and northern bedstraw are among the few wildflowers.

"Drunken" forest consists mainly of black spruce, although there are also a few small willows. Common shrubs are shrubby cinquefoil, mountain cranberry, western rose, northern black currant, northern comandra, buffaloberry, and a dwarf raspberry. Along with a heavy ground cover of soft mosses are horsetails and such wildflowers as Ross's avens, bluebells, sweet coltsfoot, a grass-of-Parnassus, a fleabane, and various sedges.


"Drunken" forest
FRED BRUEMMER

The creation of the road, however, has made an opening for other kinds of plants, including fescue, bent grasses, myriad leaf, a stinging nettle, western dock, and the colorful fireweed.

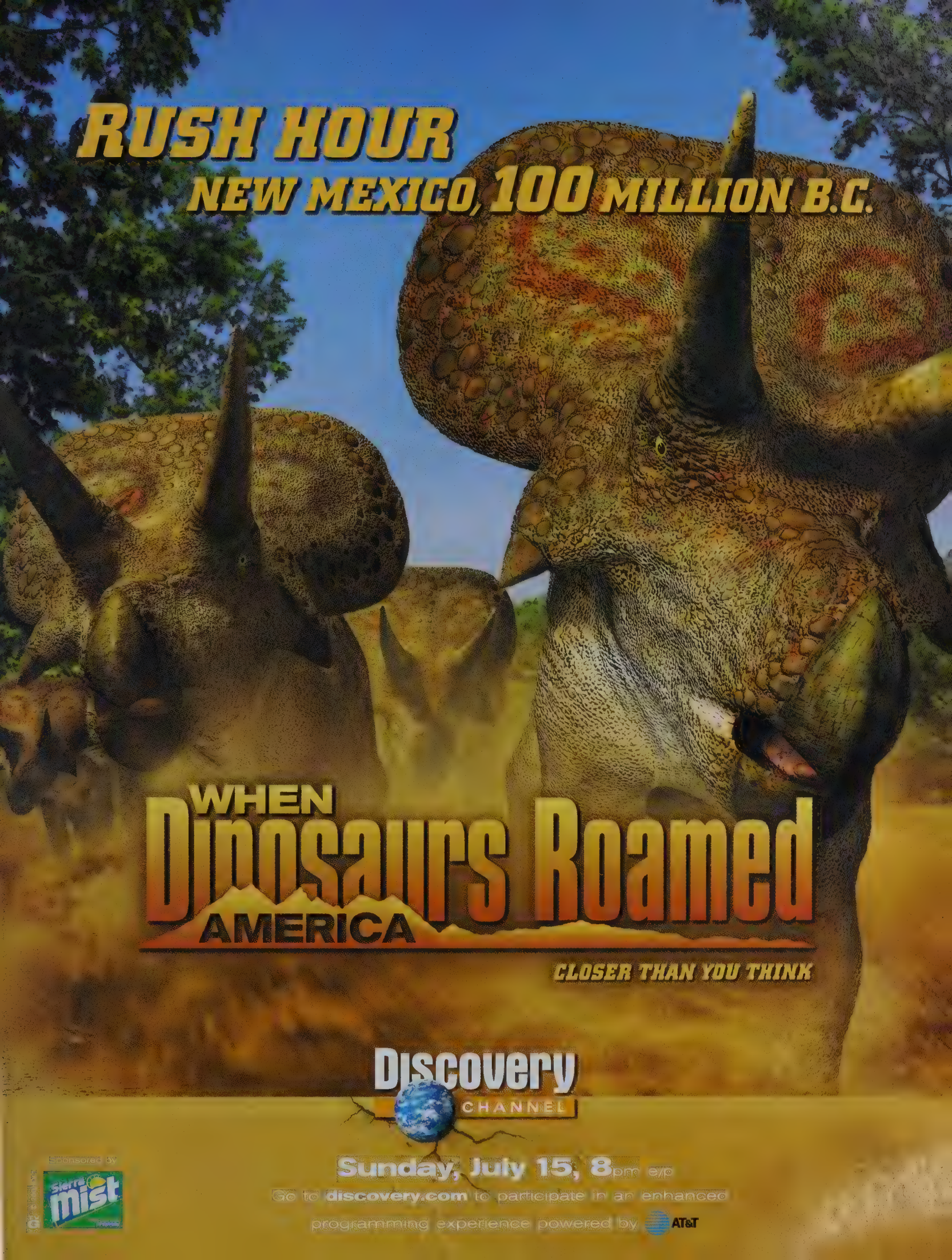
Wet meadows have abundant grasses, sedges, and rushes, while low-growing shrubs include black crowberry, mountain cranberry, shrubby cinquefoil, and three dwarf willows. Common wildflowers are a pink-flowered and a white-flowered bistort, Arctic shooting-star, three kinds of buttercups, *Parrya nudicaulis,* and Langsdorf's lousewort. Rare for the Yukon are the tiny moschatel, Sitka valerian, and *Epilobium lactiflorum* (a white-flowered, alpine willowherb).

Arctic shooting-star
MARK NEWMAN; PHOTO RESEARCHERS, INC.

Keno Hill roadside vegetation includes native forest species such as white and black spruce, alpine fir, gray alder, trembling aspen, and Scouler's willow.

Dry meadows have less species diversity than the wet meadows. Arctic willow and Labrador-tea make up the shrub population. There are three kinds of saxifrages, including the rare alpine saxifrage. The purple-headed Siberian aster is common.

Rocky summit species include the rather rare Huddleson's locoweed, a three- to four-inch-tall, hairy white plant that produces pink-to-purple flowers and oversize seed pods. Other rarities are the dwarf, shrubby *Diapensia lapponica,* whose solitary creamy white flowers are borne above a cushion of evergreen leaves, and Lapland poppy, whose yellow flowers appear on leafless stalks nearly ten inches above the basal leaves. Among the common wildflowers are one-flowered cinquefoil, woolly lousewort, alpine willowherb, three saxifrages, and an Indian paintbrush. A mat-forming shrub known as white mountain heather has minute leaves crowded into four rows. The delicate fragile fern and the larger fragrant wood fern nestle in the crevices of the sheer cliff off the northern side of the summit.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Anatomy of a Ritual

In several New World cultures, the enema was the technique of choice for taking hallucinogenic drugs. The practice was based on sound physiological principles.

By Jared Diamond

Ritual intake of alcohol and hallucinogens by enema used to be widespread among Native American tribes and is still practiced today by some. It was performed both by hunter-gatherers in the Amazon jungle and by the Maya, the most advanced indigenous civilization in the New World. But the custom may seem puzzling or bizarre to many people today. After all, if you're disposed to mind-altering drugs, it's easy just to swallow, smoke, sniff, or lick them. Why go to the trouble of taking them by enema?

The answer does not have to do with the unique beliefs of exotic cultures but with basic principles of intestinal physiology, applicable to all of us. My own research specialty as a physiologist consists of trying to figure out how our intestine is adapted for doing what nature meant it to do. Rectal administration of drugs seems to be the reverse of what's natural. How could the outcome not be disastrous if we use an orifice specifically adapted for expelling chemicals to admit them instead? But recent advances in our understanding of digestive physiology lead me to conclude that Native American enema devotees knew what they were doing. Until the modern invention of hypodermic syringes for intravenous injection, the rectal route for hallucinogens offered special advantages.

Most *Natural History* readers, insofar as they think of enemas at all, doubtless associate them not with optional entertainment but with unpleasant medical necessity. Physicians routinely prescribe enemas to clean out a patient's lower intestine before an operation or a diagnostic procedure such as a colonoscopy. As far back as the time of the ancient Sumerians, medical enemas were used to relieve constipation by washing out intestinal contents, and to eliminate parasitic intestinal worms by instilling an antiworm drug, or vermifuge (same etymology as "centrifuge," from the Latin *fugere,* to flee, but in this case the flight is from the worms, Latin *vermis*, rather than from the center). For instance, rectally administered tobacco infusions—whether employed against pinworms, roundworms, tapeworms, or threadworms—proved an effective vermifuge in sixteenth-century Europe.

These two Old World uses of enemas are easy to understand. In both cases, substances were administered by rectum, rather than by mouth, because the aim was to reach the lower intestine. There was no intent for the substances to reach the brain, and every intent for them not to. That's where traditional New World practices differed. American Indians used enemas only to administer mind-altering drugs. The rectum served not as a dead-end street but as a highway to the broad meadows of the body and brain. The enema was elevated from an uncomfortable, cold-blooded, results-oriented medical procedure to a delicious, quasi-religious ritual.

ALL PHOTOGRAPHS BY JUSTIN KERR

Self-administering a drug by enema; Maya clay figurine, A.D. 600–800

New World na-

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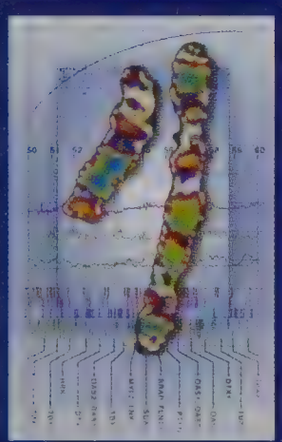
Two-time Tour de France winner
Lance Armstrong, with his son Luke.



Five years ago, cyclist Lance Armstrong was diagnosed with testicular cancer. It had already spread to his abdomen, lungs and brain. But with aggressive treatments, including three Bristol-Myers Squibb medicines, Lance conquered his cancer. He went on to win the Tour de France twice, and even to have a wonderful son—Luke.

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Hovering birds suggest the hallucinogenic possibilities of a ritual enema; Maya vase, A.D. 900–1200.

tives used many mind-altering drugs ranging from alcohol and nicotine to hallucinogens, and several of the latter were avidly embraced by drug users in the 1960s. Cocaine comes from the leaves of an Andean tree; mescaline, from the peyote cactus of Mexico and Texas; LSD analogues, from morning glory seeds; and psilocybin and psilocin, from Mexican mushrooms. With these or any other mind-altering drugs, the user's basic problem is how to get the drug to the brain. Today one can just use a needle and syringe to inject a drug into the bloodstream, but other means were needed in the days before hypodermics. While all such methods rest on the principle of getting the drug in contact with some body surface through which it will be absorbed into the blood, many choices of surface present themselves.

The most familiar choice is the small intestine, the upper stretch of our intestine just below the stomach. Coiling back and forth, the small intestine has a total length of about twenty-three feet. Its inner surface has innumerable microscopic and submicroscopic folds; smoothed out, it would cover about 5,000 square yards, comparable to the area of a football field. This enormous expanse makes the small intestine well adapted not only to its natural function of absorbing almost all the nutrients we ingest in food but also to the abnormal function of absorbing swallowed drugs.

Smoking is a popular route of drug intake for basically the same reason: microscopic folds also give our lungs a football-field-sized expanse through which to absorb oxygen and remove carbon dioxide. Still other absorptive surfaces are the tongue, the lining of the mouth, and the lining of the nose, reached through licking, chewing, and sniffing, respectively. Indians took drugs by all these still familiar routes plus two now unfamiliar ones: applying drugs to the skin and delivering them through the eyes, either by dripping them as liquids or blowing them as smoke.

The remaining absorptive surface discovered by Native Americans was the lower part of our intestine, known variously as the large intestine, colon, or rectum. To reach the other surfaces I have mentioned, all you have to do is swallow, inhale, lick, chew, or sniff (or simply expose an expanse of flesh or an eyeball). The rectal route, however, requires some mechanical props.

Perhaps the simplest prop is the suppository, a drug-impregnated plug designed for self-insertion into the anus, where the plug is melted by body heat, releasing the drug. While suppositories are a popular means of taking medicine in France, they have the disadvantage of exposing the drug to just a small fraction of the rectum's absorptive surface (the rectum is about six inches long, much longer than any suppository). Hence physicians must prescribe a considerably larger dose of any drug administered as a suppository than if the same drug is taken by mouth.

Indians devised two methods of rectal drug administration that are superior to the suppository. Both involve the insertion of a hollow bone or tube through which a drug-containing fluid is squirted deep into the rectum, thereby attaining rapid absorption across a large surface. In the first method, a helper simply fills his mouth with enema solution and blows it out through the tube. In the other, more sophisticated method, the protruding end of the tube is connected to a bulb made of an animal bladder, a leather bag, or rubber. The bulb, rather than the helper's mouth, is used to squirt the enema fluid. Thus, Indians invented the rubber-bulb syringe, now adopted worldwide for perfume atomizers and medicine droppers.

> Evidence of Maya drug-taking technology comes from colorfully painted vases unearthed by archaeologists.

Between about A.D. 1 and 900, the Maya Indians of Central America developed a highly advanced civilization; their achievements included writing, beautiful artworks, astronomy books, and a notoriously complicated calendar. When archaeologists first began to find slender tubes of unknown function in Maya tombs, they did not immediately realize that Maya sophistication also extended to enema technology. The evidence came with the

unearthing of beautiful, colorfully painted vases, some of which clearly depicted the purpose of the formerly mysterious tubes with an unmistakable clarity that made archaeologists blush. One of those vases (opposite page) shows a recumbent man with his legs spread, receiving an enema from a standing person (probably a woman) holding an enema bag. At the recumbent man's head stands a male helper ladling enema fluid out of a large jar. Another painted vase (see page 20) portrays a male god about to receive an enema from an attractive young goddess/woman standing behind him as she unties his loincloth, with an enema pot and bulb syringe ready in front of her. While we can only speculate about the ingredients, a clue is that some vases depicting enemas show containers of a foaming fluid resembling *balche,* the Maya beer that was popular at the time of the Spanish conquest and that may sometimes have been laced with hallucinogens.

But why on earth should anyone choose to administer mind-altering drugs by enema, which requires apparatus and often an assistant, instead of just swallowing the drug? Remembering that the purpose of the whole exercise is to get the drug to one's brain, I see three physiological advantages.

First, try to recall your nausea the first time you drank a lot of alcohol or inhaled smoke from a cigarette. And ask a few drug users how they felt when they first tried heroin, peyote, or psychedelic mushrooms. Most hallucinogens tend to cause nausea; even experienced Indian peyote-chewers are prone to feel sick to their stomach.

Thus, to consume mind-altering drugs by mouth can be self-defeating. If a drug stimulates vomiting, it may never reach the small intestine. In trying to take it by mouth, one may not only lose the drug but also turn what was intended as a pleasurable experience into a miserable one. By contrast, drugs taken by rectum can't produce

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Ritual enemas for a god (far left) and a traveler (second from right); Maya vase, A.D. 750–950

nausea by irritating the stomach or the small intestine. Even if you do vomit, you retain the drug, because vomiting expels the contents of the stomach and upper small intestine but not of the large intestine.

The second advantage that enemas have over swallowing stems from the following facts of physiology: To get a "high" from a drug, you want to absorb it quickly so that it will reach a high concentration in the blood and brain. That's why intravenous injection is so effective—a needle-injected substance reaches the brain in less than half a minute. In the prehypodermic era, the fastest means of drug delivery was by enema.

From this perspective, swallowing is inefficient. Anything you swallow has to traverse your stomach before it can get absorbed through your small intestine. If your stomach already contains food, the drug that you swallow may sit in your stomach for hours until the food is ready for release into the intestine. This problem is compounded for the class of chemicals termed alkaloids, which includes most drugs of abuse: heroin, cocaine, nicotine, mescaline, LSD, and others. In chemical jargon, alkaloids are bases. What this means, in effect, is that when alkaloids reach the stomach, which secretes acid, they bind with a hydrogen ion and their absorption rate slows greatly. Hence, alkaloid absorption is negligible in the stomach and retarded in the small intestine. But this problem of retarded absorption doesn't arise in the rectum, because the rectum doesn't secrete acid. Rectal administration of alkaloids approaches the effect of mainlining them into a vein with a stroke of a hypodermic's plunger.

The remaining physiological virtue of delivering drugs by enema is that they bypass the small intestine's private line to the liver. While blood from the rectum goes straight into our general circulation and thence via the heart to the brain, blood from the small intestine goes first to the liver, which acts toward drugs as the bouncer at the nightclub door acts toward undesirable customers. One of the liver's functions is to admit absorbed nutritious foodstuffs into the general circulation but to weed out drugs and poisons that entered the small intestine accidentally or through our perverse intentions. The long list of drugs thus weeded out by the liver includes alcohol, cocaine, morphine, nicotine, and tetrahydrocannabinol (the active ingredient of marijuana).

In short, when you swallow a drug, it inevitably ends up in your liver, whose job is to prevent you from doing exactly what you are trying to do: get that drug to your brain. Circumventing that dilemma is the main reason for using any route of drug administration other than the stomach and small intestine—such as the lungs, nose, tongue, mouth, eyes, or rectum. But numerous drugs that you wouldn't want in your lungs or eyes are tolerated by the rectum.

At the risk of belaboring the obvious, I'll conclude by stressing why this piece shouldn't convince you to rush out and give yourself (or ask your beloved to give you) a hallucinogenic enema. Every argument against taking hallucinogenic drugs by any route applies with full force to the enema. Drugs destroy your body slowly if used carefully. They kill you quickly if used carelessly. They cut off your access to all the diverse and persistent pleasures of a normal life, in return for brief flashes of a single sickening pleasure. Added to all those general arguments, drug enemas pose other risks of their own. They are so tricky to administer correctly that they can easily cause severe poisoning or death. Native Americans knew that they had to leave enema administration to an expert elder.

It's ironic that some of the same drugs that Indians learned to handle safely are today causing terrible and widespread problems in our society. While the drug enema is an old tradition in the New World, the groups that indulged in the practice had the good sense to reserve it for rare ritual occasions. The extreme care and relative infrequency (compared with drinking and smoking) with which the custom was practiced by the very people who invented it testifies to their understanding of its dangers.

Jared Diamond is an intestinal physiologist and evolutionary biologist at UCLA. His book Guns, Germs, and Steel: The Fates of Human Societies *won a 1998 Pulitzer Prize.*

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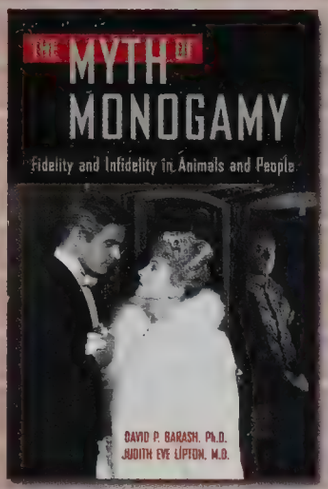

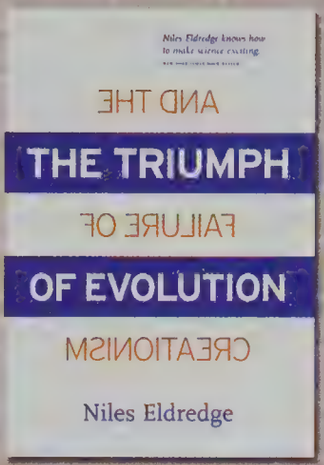

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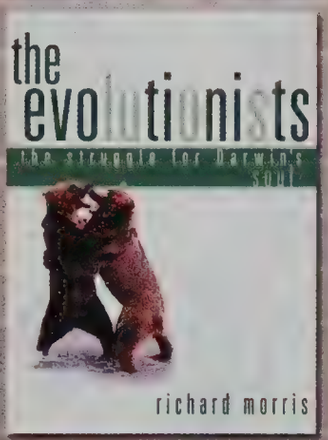

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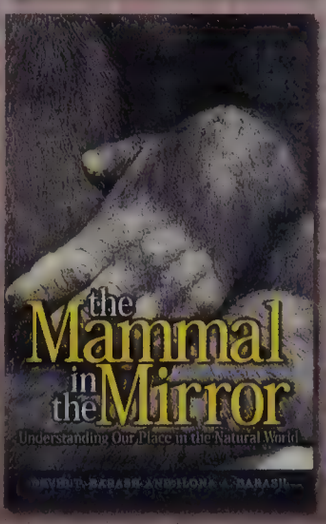

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UNIVERSE

By Any Other Name

When it comes to plain speaking, astrophysicists claim bragging rights.

By Neil deGrasse Tyson

The chief merit of language is clearness, and we know that nothing detracts so much from this as do unfamiliar terms.

—Galen (A.D. 129–ca. 216)

Do you know what term medical doctors have for one of the bones in your big toe? Ungual phalanx of the hallux. Do you know the official term that astrophysicists use for the beginning of the universe? Big bang. Why does it take nine syllables to name a bone in your toe but only two syllables to name the origin of all the space, time, matter, and energy in the cosmos? Something is wrong.

Doctors are not uniquely guilty of sesquipedalian transgressions, but they certainly lead the way. The community of astrophysicists, however, proudly wields simple words, even for our most complex concepts. Not only do our terms typically have few syllables, they also tend to be descriptive and, in some cases, just fun to say. Medicine and astrophysics are probably polar opposites in the name game, with other professions filling in the middle.

Despite the scowls of my geologist colleagues, I have not managed to remember what plagioclase feldspar looks like, and I am still wondering what's so friendly about migmatitic gneiss. Perhaps geologists should pass a law against words of more than eight syllables. That way, I would never have to pronounce "uniformitarianism," whether or not it's an important doctrine.

When ichthyologists go home at night, do they see *Carassius auratus* instead of goldfish swimming in their fishbowls? Can anyone get more obscure than biologists and paleontologists, who reflect for thirteen syllables on whether or not ontogeny recapitulates phylogeny? In such cases, you feel especially ignorant, because you trip over the words just trying to pronounce them. Should I confess to the authorities, here and now, that I have occasionally snorted oxymetazoline hydrochloride? Yes, I inhaled all ten syllables as the active ingredient in my nasal decongestant spray.

And how about those dozen roses I just gave my wife? Do botanists give each other a dozen *Rosa nutkana* instead? One of the best known lines in Shakespeare is the romantic utterance of Juliet, who declared that a rose by any other name would smell as sweet. True, but what she neglected to mention is that a rose by a five-syllable botanical classification scheme rarely makes its way into iambic pentameter.

The parade of extinct species, with names from *Archaeopteryx* to *Zalambdalestes,* would leave most heads spinning, although one of the great mysteries of the universe is how eight-year-old kids seem to have no trouble with the taxonomy of extinct ferocious beasts.

Sociologists, professional educators, and literary critics are just as bad (or perhaps worse) than scientists. Is there some tablet in the sky upon which is inscribed a commandment requiring sociologists to refer to your neighbor as a residential propinquitist? Accuse someone in New York City of being one, and you might suffer a bruised jaw—or would that be a mandibular contusion? When I was a schoolboy, the one-syllable word "test" did the job. Today you can hardly find the term in the discourse of professional educators. A test has become "an assessment instrument." And much as I have tried, I still cannot understand the following randomly chosen passage in the 1991 book *Deconstruction: Theory and Practice,* by Christopher Norris, a British professor of English:

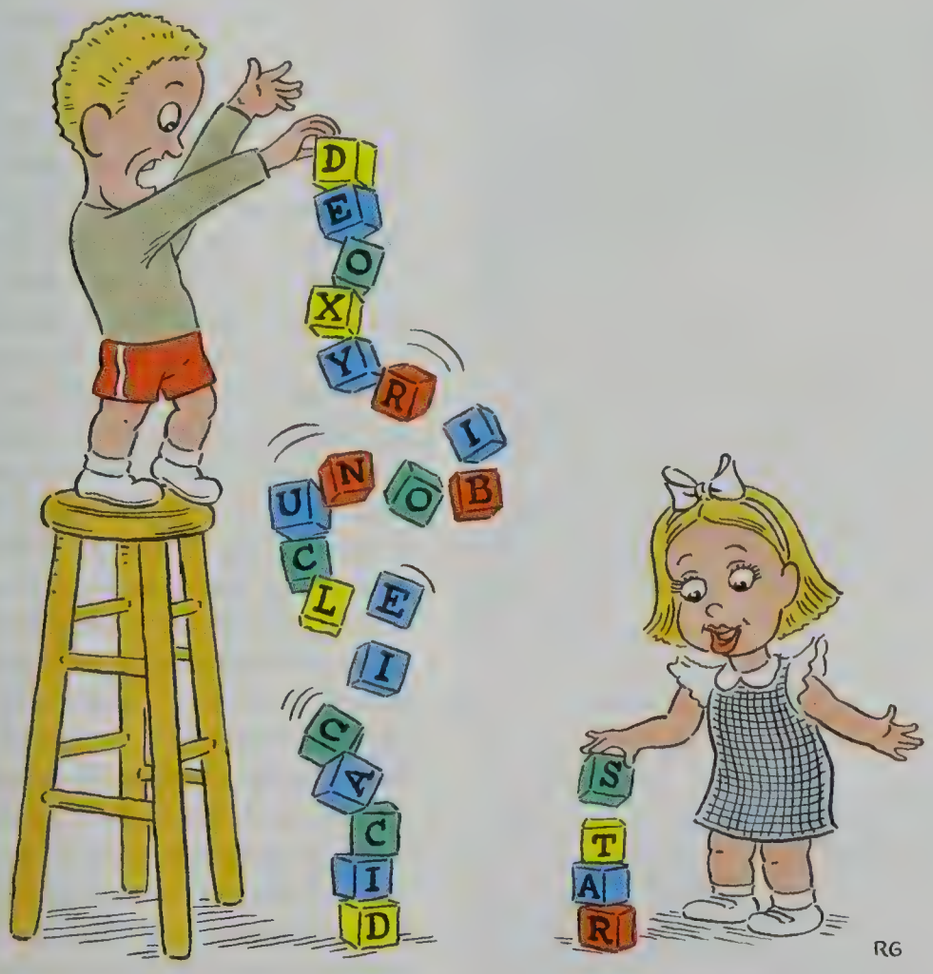
> *But the point of these metaphors is not to reinstate a thematics of presence or expression, as opposed to the* differance *of structural inscription. Rather, it is to demonstrate that structuralism itself arises from the break with an attitude (the phenomenological) it cannot reject but must perpetually put into question.*

Maybe it's not a beginners' book on deconstruction. Maybe beginners' books don't exist on the subject. Or maybe I'm just stupid, and all the people who speak this way are brilliant thinkers. If not, then their work is easier to understand than they let on, and their jargon erects a downright opaque psychological boundary between those who know and those who don't.

The renowned physicist Richard Feynman, in an essay entitled "What Is Science," written for a 1969 issue of *The Physics Teacher,* recalled a childhood conversation with a friend:

> *We were playing in the fields and this boy said to me, "See that bird standing on the stump there? What's the name of it?" I said, "I haven't got the*

slightest idea." He said, "It's a brown-throated thrush. Your father doesn't teach you much about science." I smiled to myself, because my father had already taught me that . . . "even if you know all [the] names for it, you still know nothing about the bird. . . . Now that thrush sings, and teaches its young to fly, and flies so many miles away during the summer across the country" . . . and so forth. There is a difference between the name of the thing and what goes on.



ROBERT GROSSMAN

Feynman's dad was basically right, but if we take his argument to the extreme, we would all stare at each other, mute in the forest. So we obviously need words for things before we can communicate ideas that relate to them. And in the sciences, words for things can be precise, historical, and even illuminating. But I remain intrigued that in social settings such as cocktail parties, you will impress people more with the obscurity of your vocabulary than with your actual command of a body of knowledge.

I submit that the widespread public interest in cosmic discovery, measured by frequency of headlines, may be fueled partly by the transparency of astrophysical jargon. When writing a newspaper article, a journalist can swiftly reach the substance without wasting precious column length introducing and defining terms. Our simple and occasionally fun jargon uncloaks what are truly complex concepts and grants the reporter and the public an opportunity to think about the ideas rather than puzzle over the names of things.

Astrophysicists eschew big words and the general latinization of terms—although I wonder if our vocabulary would be different if Latin were a living, vibrant language. In any case, we simply tell it like it is. We started with the big bang, but let's keep going: What do we officially call big red stars? Red giants. How about big blue stars? Blue giants. Or small white stars? White dwarfs.

How about that official term for spots on the Sun's surface? Sunspots. Or that persistent red spot in Jupiter's atmosphere? Jupiter's Great Red Spot.

Want dark mysteries? We call the early period in the universe—the time before the first stars were born—the dark ages. Ninety percent of all the gravity in the universe comes from a substance that neither emits nor absorbs light in any form. We call the offending stuff dark matter. And the universe is not only expanding but was recently discovered to be accelerating as well, by the action of an unknown energy that fills the vacuum of space. What else could we call it but dark energy?

While we are being dark, let's not forget that there are regions of the universe where the gravitational forces are so strong that if you fell in you would never get out. So strong is the gravity that space and time have curved back on themselves, preventing not only you, but even light, from escaping. I challenge you to invent a better term than black hole.

The way astrophysicists name gas clouds in our own Milky Way galaxy is not fundamentally different from what you did as a kid when you lay on the beach gazing at the puffy cumulus clouds that drifted by. Our list is rich in simple imagery. Want a sampling? We've got the Cat's Eye Nebula, the Crab Nebula, the Dumbbell Nebula, the Eagle Nebula, the Horsehead Nebula, the Lagoon Nebula, the North American Nebula, the Ring Nebula, the Tarantula Nebula, and the Veil Nebula. We even name entire galaxies this way, such as the Pinwheel Galaxy, the Sombrero Galaxy, and the Whirlpool Galaxy. Sure, each of these objects has an official numerical designation in a formally compiled catalog. But in professional research publications and in scientific par-

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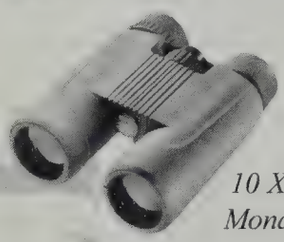

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lance, the formal designation is not a substitute for the common, descriptive term (when one is available).

Whenever specialized vocabulary is simple and fun, the words can slide into the language of commerce and culture. This fact has placed the names of our most cherished objects and concepts within reach of everyone. The list is long and impressive. Who among you has not sipped Celestial Seasonings tea? Or taken a bath using Moon Glow bath beads? I have yet to taste Kentucky Fried Chicken's recently introduced Big Bang sandwich, but I can imagine that its flavor must be intense.

Even so, no matter how accurate Pulsar brand watches are advertised to be, their timekeeping precision pales in comparison with the original rapidly rotating neutron stars of the same name. Black holes are what people perceive as one-way phenomena, such as paying taxes or feeding the financial needs of teenagers. And no matter how quickly my Quasar brand microwave oven cooks food, the original quasars at the edge of the universe would cook it much, much faster.

Of course, stars twinkled in the sky long before the noun *star* and the verb *star* ever applied to movie actors.

I am too young to have driven Ford's Galaxie 500, a prototype of the land yacht, but my wife's first car was a Chevy Nova. I believe that if General Motors knew that a Nova was a star that had just exploded, they might have reconsidered the name.

Saturn automobiles remain as popular as the planet itself. We know the company is named after the planet and not the god because the company's logo is a tilted, stylized, ringed orb. The real Saturn is light enough for any scoop of it to float on water. I wonder (although don't really wish to test) whether the Saturn car will float, too.

Mercury is an entire division of the Ford Motor Company, while the Mitsubishi Corporation has a car called the Eclipse. And the peculiar connect-the-dots diagram on the back of all Subaru automobiles is a representation of the famous Pleiades star cluster in the constellation Taurus. Indeed, the Japanese call the Pleiades "Subaru."

No doubt the most famous molecule in biology is deoxyribonucleic acid—ten syllables. Even when abbreviated, it still has three syllables: D-N-A. Has anyone adopted this term for anything besides science writing? To sell products? To write a jingle? On hearing it, is anyone driven to compose verse? As of this printing, there are no cars named after latinized biological species or medicinal ingredients.

Of course, we in the astrophysics community are not totally without polysyllabic guilt. In the Germanic tradition of slapping words together to make an even bigger word, some of our terms can make strong men weep. My favorite in this category is magnetohydrodynamics, which is the study of plasmas and their interplay with electromagnetic fields. In this particular case, the subdiscipline happens to be as complicated as the word that describes it.

By the way, we also have some misleading terms—such as planetary nebula, which has nothing whatever to do with planets. William Herschel first observed and described these nebulae in the eighteenth century, with the help of the world's then-largest telescope. The circular fuzzy disks loosely resembled the little circular images of planets he had studied.

We also use the first word in the phrase "amateur astronomer" to mean something different from what you might expect. While you probably wouldn't be drawn to an advertisement for an amateur neurosurgeon or an amateur attorney, you are always in good hands with an amateur astronomer. It's a title worn proudly by those for whom the night sky is a playground of objects and phenomena. Amateur astronomers, as a group, monitor the sky more than anybody else, professionals included. In so doing, they discover and track

comets, asteroids, supernovas, variable stars, and all manner of transient cosmic phenomena. They are indispensable to the health of the field.

Astrophysicists also use at least one term that makes chemists cry. We freely describe the thermonuclear fusion of hydrogen in the centers of stars as burning. Since the act of burning is a strictly chemical process, and since what goes on in the center of a star is strictly nuclear, we are guilty as charred.

And we do have one or two tongue twisters. In case you didn't know, Earth, the Moon, and the Sun are in syzygy every time they line up in space. And our official term for the angle between Earth's equator and the plane of Earth's orbit around the Sun is the obliquity of the ecliptic—but we are not proud of this fact.

Among its numerous duties, the International Astronomical Union (IAU), the professional society of the world's astrophysicists, makes the rules of nomenclature. In many cases, however, a naming scheme or term gets established only after it has enjoyed wide use by the profession. Consequently, rulings by the IAU are often the formal recognition of an already existent naming trend. This approach to the jargon of a discipline tends to preserve the history, spontaneity, and novelty in scientific discourse. For these reasons, cosmic discovery will likely remain forever attractive and accessible to the general public and to the creative energies of authors, artists, and producers.

We might therefore credit (in part) the public's vicarious joy in cosmic discovery to the astrophysicist's monosyllabic lexicon—an assortment of terms that by any other names would leave you stalled in the dictionary, more in awe of the words than of the concepts themselves.

Astrophysicist Neil deGrasse Tyson is the Frederick P. Rose Director of New York City's Hayden Planetarium and a visiting research scientist at Princeton University.

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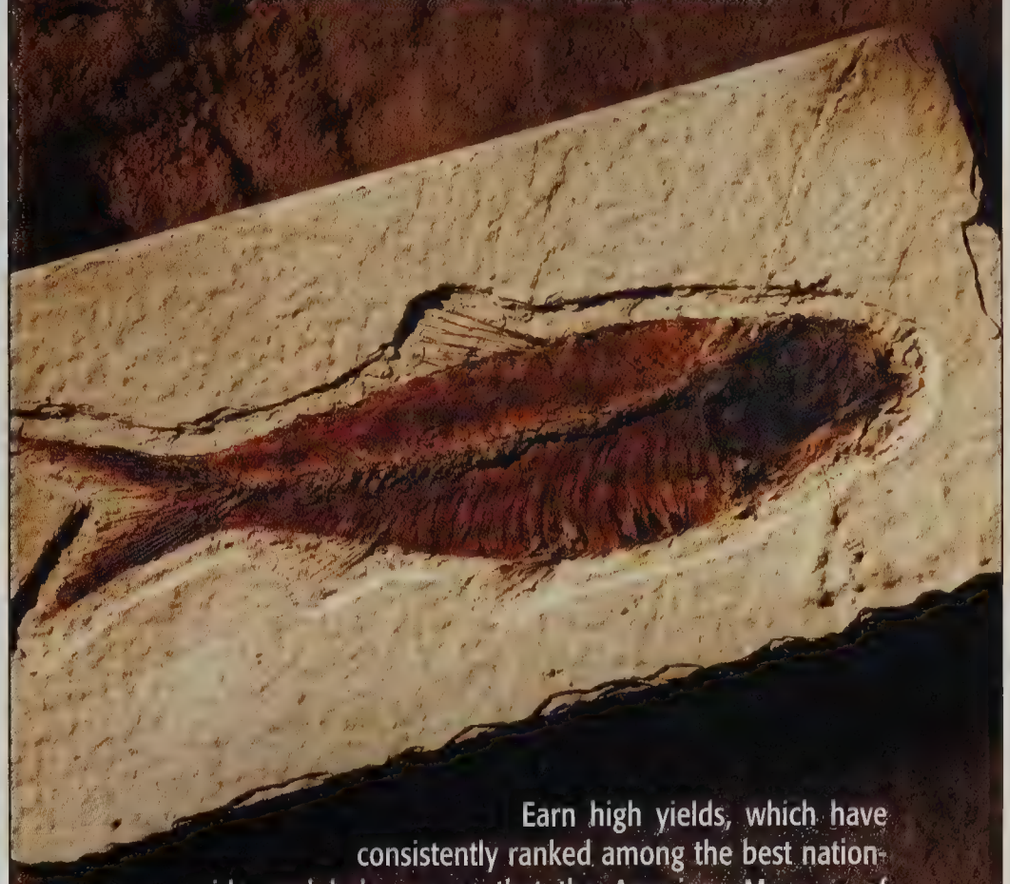

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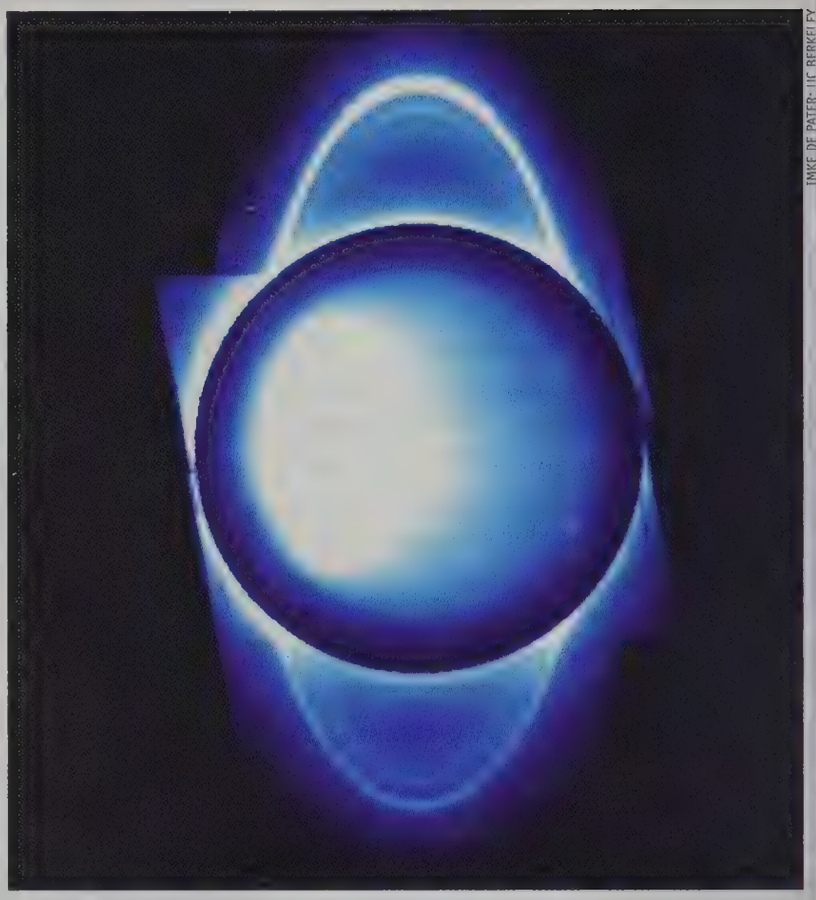
CELESTIAL EVENTS

Blue Light Specials

Uranus and Neptune are ready for their close-ups—again.

By Richard Panek



Uranus, as imaged by the Keck II telescope

In January 1986, *Voyager 2* flew near Uranus and found it to be big and blue and featureless. In August 1989, *Voyager 2* swept past Neptune and found it to be big and blue and featureful—roiling with brief, fierce storms. But that was then. Now astronomers are finding that these two planets aren't quite what they seemed at first glance.

Of course, they're both still big—almost identically so. The diameters of Uranus and Neptune at their equators are 31,763 and 30,775 miles, respectively, making them the third and fourth largest planets in the solar system. And they're both still blue, due to the absorption of red light by the methane in their atmospheres. But astronomers already knew that much about Uranus and Neptune before *Voyager 2* was launched in 1977.

Back then, even the most powerful telescopes on Earth couldn't resolve either planet into much more than a small bluish disk. Uranus's orbit takes it anywhere from 19 to 21 astronomical units (AUs) away from Earth, and Neptune's, from 29 to 31 AUs (one AU is equal to the average distance between Earth and the Sun, about 93 million miles). That means they are, respectively, twice and three times as far from Earth as the next farthest planet, Saturn.

Even in the aftermath of *Voyager 2*'s 1986 visit, Uranus still appeared to be a serene gaseous planet. Not until years later did computer enhancements of the data begin to reveal rapidly rotating bands of clouds in the planet's atmosphere—features that subsequent Hubble Space Telescope observations first confirmed and then amplified. Gone was the image of Uranus as a blank blue marble; in its place now churns a turbulent cauldron.

Perceptions of Neptune have recently been undergoing a similar metamorphosis. Just last year, a team of astronomers used the 10-meter Keck II telescope's new adaptive optics system (a technology that greatly compensates for the blurring effects of Earth's atmosphere) to study Neptune's highly volatile atmosphere. Hubble observations had already indicated that massive storms on Neptune might be popping into and out of existence, but this new information has added unprecedented detail. "This shows us how much structure there is in the planet's atmosphere, how dynamic it is—as dynamic as Jupiter's," said the project's lead astronomer. Gone is the initial image of Neptune as merely the more active twin of Uranus; in its place now seethes, well, another Jupiter.

But what's been changing since the *Voyager 2* flyby isn't only the quality of the data. In the case of Uranus, it's the planet itself. Both because Uranus orbits the Sun once every 84 Earth years and because relative to the plane of the solar system it rotates on its side (presumably due to an ancient collision with a massive object), the northern hemisphere of the planet, which is just now coming into view, has been in darkness since the 1960s. In terms of current observational technology, that's nearly forever. Astronomers studying the planet's newly emergent hemisphere have already detected stark distinctions between the clouds there and those in its southern

hemisphere—differences in color, brightness, and altitude.

Are these variations seasonal or permanent? Are the clouds in Uranus's northern hemisphere a result of the Sun's warming of the atmospheric gases? Will those clouds, over time, come to resemble their southern hemisphere counterparts? Only a decade ago, the major question underlying all these considerations—just how *un*featureless Uranus really is—would have been nonsensical. Now, thanks to adaptive optics, astronomers will actually be able to observe the planet long enough to find the answer.

You, however, won't—unless you have access to Hubble or Keck II. But you will be able to take advantage of the year's best opportunity for amateurs to observe Uranus and Neptune, both of which will be rising throughout the summer soon after nightfall in the southeastern sky. On July 30, Neptune reaches opposition; at magnitude +7.8, it won't be visible without binoculars, at the very least. Then on August 15, Uranus also reaches opposition; at magnitude +5.7, it might be barely visible, under ideal viewing conditions, with the naked eye. To observe either planet, a good star chart is a must. What you'll see, at best, is the same bluish disk people have always seen—the planetary equivalent of "That was then." But for the first time, you'll also be able to begin filling in the details, and to know "This is now."

Richard Panek is the author of Seeing and Believing: How the Telescope Opened Our Eyes and Minds to the Heavens *(Penguin, 1999).*

THE SKY IN JULY AND AUGUST

By Joe Rao

Mercury is above the east-northeastern horizon at dawn during the first weeks in July. On the 9th, it will reach its greatest western elongation from the Sun, rising about one and a half hours before sunrise. Shining at magnitude +0.5, the innermost planet can be seen (with only slight difficulty) about 14° above the east-northeastern horizon. Mercury and a brighter Jupiter (emerging out of the solar glare) approach each other, with Mercury passing 1.9° below and to the right of the gaseous giant on the 13th. By late August, Mercury moves to the western evening sky and, in contrast with July, has a very poor apparition—its worst in 2001.

Venus rises an hour or more before morning twilight in early July, despite being many weeks past its greatest elongation. Although fading slightly, this lanternlike planet is still a spectacular sight as it lifts up early in the morning in the east-northeast. On the morning of July 13, binoculars trained on Venus will reveal the third-magnitude star Epsilon Tauri, or Ain, just 0.1° from Venus. The following morning, Venus passes 3° north of Aldebaran. On July 15 you'll be able to see both Venus and Saturn within the same field of a low-power telescope. As dawn arrives over North America on July 17, Venus and Saturn shine low in the east near the waning crescent Moon, which creeps closer to the planets as they fade from view in the brightening sky. If you follow the pair with a telescope, picking them up against a clear daytime sky, you'll see the Moon actually pass in front of Venus. The occultation is visible over the whole continent, occurring between 2:30 and 3:30 P.M. in the eastern and central regions, late morning to midday in the west, and midmorning in Hawaii. All during August, Venus hangs at about the same place above the dawn horizon. Early in the month, the planet attains the highest altitude of its current apparition. Jupiter passes nearest to Venus on the mornings of August 5 and 6, and the Moon skims past it on August 16. On the morning of August 26, Venus forms a striking line with Castor and Pollux (above and to the left of the planet).

Mars, although fading rapidly from its peak of brilliance in June, still shines at brighter than -2.0 magnitude through July 11 and remains brighter than Sirius through August 2. By the end of August it dims to -0.9 but still manages to outshine the brightest star of the summer sky—the similarly hued Arcturus—by half a magnitude. Throughout July and August, you'll find Mars glowing in the south-southeast at dusk. The Moon will be nearby on the evenings of July 2 and 30 and August 26 and 27.

Jupiter rises early in July during morning twilight on the east-northeastern horizon. On the morning of the 13th, Mercury is nearby, passing less than 2° to the south. Jupiter is plainly visible on July 18 below and to the left of a slender Moon. In August the planet rises at about 3 A.M. local time on the 1st and at about 1:00 A.M. local time by the 31st. Venus passes by Jupiter on the mornings of August 5

and 6. Next to Venus, Jupiter is the most brilliant predawn "star." If you're outside during morning twilight in August, look east to spot both Jupiter and Venus: the last pair of starry lights to fade before the coming of day. The Moon is not far from Jupiter on August 15.

Saturn is visible in the morning sky during both July and August. Between July 11 and 17, it rises a few hours before sunrise and joins dazzling Venus and the ruddy star Aldebaran to form a trio (all fitting within a 5° circle). On the morning of July 15, Venus can be found just 0.7° south of Saturn. Two mornings later, the waning crescent Moon joins the gathering. In August Saturn rises soon after midnight. The Moon forms a triangle with the planet and Aldebaran on the morning of August 14. The planet's rings are now tipped at 26.2°, and in sunlight they cast a noticeable shadow on the planet, rendering its appearance strikingly 3-D through a telescope.

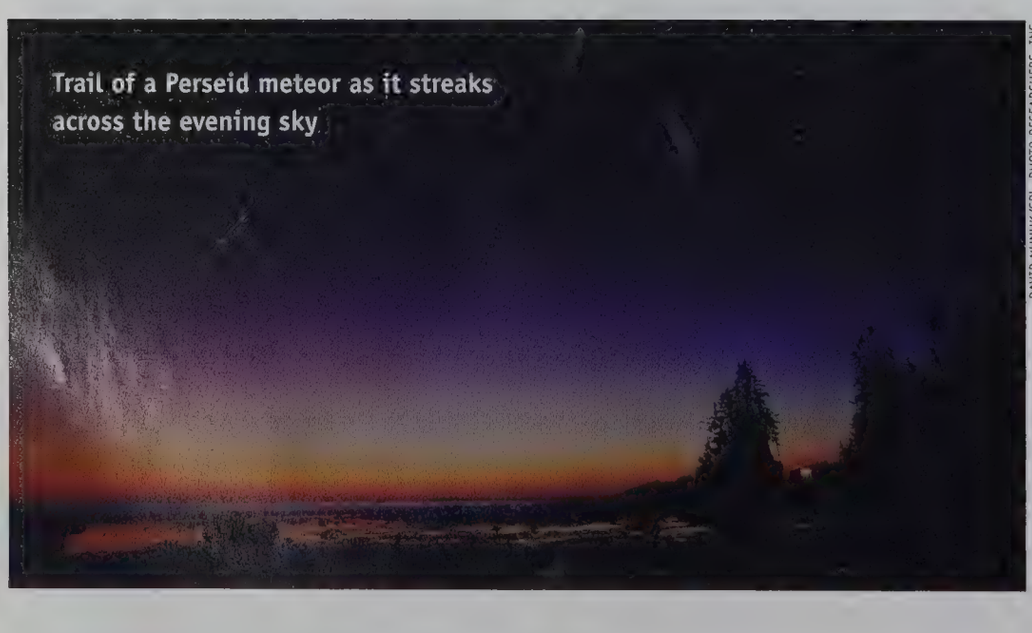
The Moon is full on July 5 at 11:04 A.M., and a partial lunar eclipse, visible in the United States only from the Aleutian Islands and Hawaii, occurs with this full Moon. It begins to enter Earth's umbra at 3:35 A.M. Hawaiian Standard Time (HST); deepest eclipse, with the upper half of the Moon's diameter in shadow, occurs at 4:55 A.M., HST. Last quarter comes on July 13 at 2:45 P.M., new Moon falls on July 20 at 3:44 P.M., and first quarter is on July 27 at 6:08 A.M. Full phase in August occurs on the 4th at 1:56 A.M., last quarter on the 12th at 3:53 A.M., new Moon on the 18th at 10:55 P.M., and first quarter on the 25th at 3:55 P.M.

A planetary lineup from mid-July to mid-August will make it worthwhile getting up about an hour or two before sunrise. Mercury, Jupiter, the Moon, Saturn, and Venus will be hanging low in the eastern sky, forming a striking line best viewed at about 5:00 A.M. on July 18.

Earth is at aphelion—its farthest point from the Sun—94,502,836 miles—at 10 A.M. on July 4.

The Perseid meteor shower will reach its peak on the night of August 11–12. These bright, swift streaks appear to emanate from the vicinity of the constellation Perseus (hence the name Perseid). Unfortunately, the bright Moon is at last quarter and not far from the "shooting stars" during their peak, but a fair number of Perseids may be seen for a few nights before and after the peak.

Unless otherwise noted, all times are given in Eastern Daylight Time.



Trail of a Perseid meteor as it streaks across the evening sky

DAVID NUNUK/SPL; PHOTO RESEARCHERS, INC.

IN SUM

Chemical

BEE BOUQUET When a bumblebee finds a nectar-rich flower, it tags the blossom with a scent mark, identifying the flower as being worth a return visit. Since bumblebees are social insects that work for the good of the colony, researchers suspect that individua

MARTIN GARWOOD; NHPA

Solitary bee feeding on nectar

members of a hive leave marks that help thei hivemates find the best blossoms.

Solitary bees are a different story. Foraging only for her own young, each female is in direct competition with all others of the same species. But Francis Gilbert, of the University of Nottingham, and colleagues have shown that solitary bees also rely on scent markings to identify the best food sources.

Working for six years at study sites in Portugal, the researchers studied females of the solitary bee *Anthophora plumipes* as they foraged for the nectar of honeywort flowers. The team found that, like bumblebees, solitary bees rely on at least two separate components in their scent markings. One is a self-repellent that wears off within about thirty minutes, dissipating as the plant renews its stock of nectar. By the time the flower once again has a full supply, the scent has degraded to the point that the bee is no longer repelled by it. The other component is a short-term attractant, lasting less than three minutes. The scientists suggest that the bee might use this mark if it doesn't extract all the available nectar during an initial visit, facilitating a return within seconds to finish the job. So far, however, it is unclear why a bee doesn't—or can't—remove al

Talk

New findings expand our understanding of communication in the animal kingdom.

the nectar the first time it feeds at a blossom.

A. plumipes females appeared to respond differently to different individuals' scent marks. The bee that made the most visits to blossoms in each flower patch—dubbed the major bee—ignored the marks made by others and laid her own mark on top of them. The other bees avoided the flowers she had marked. The researchers thus suspect that the scent marks may also be a way for the dominant female to remind her neighbors she's top bee. ("Individually Recognizable Scent Marks on Flowers Made by a Solitary Bee," *Animal Behaviour* 61:1, 2001)

SAVVY SPIDERS All animals—even predators—have to avoid being eaten. One way to dodge an untimely demise is to gather information about potential predators in advance of an attack.

The wolf spider *Pardosa milvina* does all it can to avoid being swallowed by *Hogna helluo,* a much larger wolf spider that occupies the same habitat. Zoologists at Miami University in Ohio and Susquehanna University in Pennsylvania have recently demonstrated that the smaller spider is able to decode chemical cues left by the larger one, and to change its behavior accordingly.

The researchers divided the larger spiders into two groups. One group was fed only *P. milvina,* the other only crickets. Both groups were then allowed to wander across sheets of filter paper. After removing the predators, the scientists lined one enclosed area with the exposed filter paper (which held traces of *H. helluo*'s silk and excrement) and another with clean paper. The smaller spiders were then released into both areas, and their activity levels were monitored. (The larger spiders usually prey on moving targets; inactivity is thought to be an important way for a prey species to avoid attack.)

ERIC STASHAK; SUSQUEHANNA UNIVERSITY

Wolf spiders, large and small

The spiders placed on the paper with chemical cues from *H. helluo* were much more likely than those placed on clean paper to stop moving altogether. In addition, they reacted more strongly to cues from spiders that had been fed *P. milvina* than to cues from those that had been fed crickets. Detecting such differences is key to assessing danger, since *H. helluo* consistently prefers to attack one type of prey in the wild. (In a previous study, the researchers found that *H. helluo* also reacted to chemical cues, preferring filter paper that had been exposed to whatever it was fed—either the smaller spiders or crickets.)

For the smaller spiders, holding still may be an important way to avoid being eaten, but there are, after all, some costs associated with inactivity—it doesn't allow the smaller spider to do much reproducing or eating of its own. Fortunately, *P. milvina*'s fine-tuned sensing system makes it possible for the species to resort to inactivity only when absolutely necessary. ("Wolf Spider Predator Avoidance Tactics and Survival in the Presence of Diet-Associated Predator Cues [Araneae: Lycosidae]," *Animal Behaviour* 61:1, 2001.)

REPULSIVE NEWTS Both vertebrates and invertebrates use chemical signals—pheromones—to communicate with others of the same species during the mating game. In most species, the pheromones act as attractants and sexual stimulants. Some invertebrates have also been shown to produce repellents that drive away competitors. Now biologists Daesik Park and Catherine Propper, of Northern Arizona University, have found evidence that in at least one vertebrate species—the red-spotted newt *(Notophthalmus viridescens)*—a pheromone produced by courting males repels rivals.

Placing different combinations of males and females in the arms of a Y-shaped maze, Park and Propper introduced a test male into the base of the maze and allowed him to choose, based only on the odor cues he received, which arm of the maze to enter.

The researchers found that the test male was influenced by the concentration of repellent pheromones he encountered and was more likely to approach a lone female than one in the company of males. Males that had been exposed to females were less often approached by the test newt, suggesting that males have to be in the presence of a female to effectively repel a rival.

MICHAEL LUSTBADER; PHOTO RESEARCHERS, INC.

Red-spotted newts

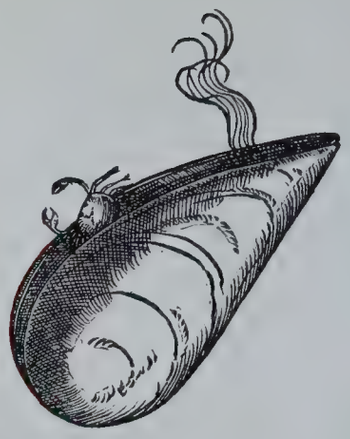
The repellent function may benefit all males by allowing the initial suitor to continue his courtship without conflict, while potential rivals channel their energies into finding a solitary female, with whom the chances of success are likely to be greater. ("Repellent Function of Male Pheromones in the Red-Spotted Newt," *Journal of Experimental Zoology* 289, 2001) —*Kirsten L. Weir*

IN THE FIELD

Mussel-Bound Crab

A naturalist plays hide-and-seek with a tiny crustacean.

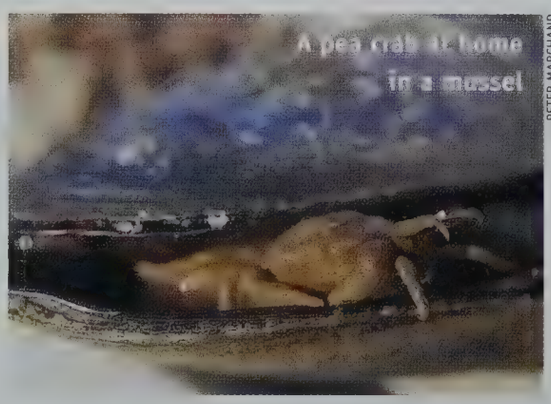
By Peter J. Marchand



FROM *LIBRI DE PISCIBUS MARINIS*; PHOTO J. BECKETT, AMNH

My search for the elusive pea crab began almost a year ago on the rocky coast of northern California. It was a matter of simple curiosity at first—chasing down yet another fascinating story of animal diversity in the intertidal zone—but the longer it took to find the crab, the more obsessed I became. Before my quest ended, I had crisscrossed the United States twice, talked with fishermen on Cape Cod, recruited the assistance of a diver on Maui, engaged the services of oystermen and a marine biologist at Chesapeake Bay, and even had a few New England chefs looking on my behalf. I was in Rhode Island when I finally laid eyes on a pea crab—on the tailgate of my truck.

Not that the pea crab is rare. One species or another in the genus *Pinnotheres* can be found on both sides of the Atlantic and Pacific Oceans. And they've been the subject of study from the British Isles to Brazil and from California to Taiwan. My difficulty in finding them had to do with their unusual habits. The male, impossibly small and cryptically colored, is skittish; the female lives most of her life out of sight—inside the shells of live mussels, oysters, scallops, and clams and in the tubes of the marine worms known as polychaetes. And like many small animals in ever changing environments, their numbers rise and fall. You might find a crab in eight out of ten shellfish, or you might find none. Everywhere I went, there had been "plenty the week before," according to locals, but none at the moment I was inquiring. I just couldn't hit it right until David Beutel, of the University of Rhode Island's Fisheries Center, put on his boots to help. Wading into the submerged tide pools at Black Point on Rhode Island Sound, he probed among the rocks, plunging his arms into the chilly water to grope for dense clusters of mussels held together with intertwined strands of algae. Soon he emerged with a half-full bucket containing several dozen medium-sized mollusks. I carried the shells over to the back of my truck and went to work with a shucking knife. Within a few minutes I sighted my first pea crab, hunkering in the shadowy interior of a living mussel.



A pea crab at home in a mussel

PETER MARCHAND

Pea crabs are appropriately named, not just for their small size but for the female's resemblance in shape and texture to a slightly flattened pea or bean. Soft and succulent looking, this crab was a female with a caramel brown coloring that matched rather closely the shade of the mussel's flesh (females occupying other shellfish range from white to salmon pink, but whether this coloration is adaptive is unknown). Although the mussel I found it in was less than two inches long, the crab had grown to nearly half an inch, exclusive of its legs, and occupied almost a quarter of the mussel's mantle cavity—not bad, considering the crab's inauspicious start.

All pea crabs begin their lives as free-swimming larvae less than a millimeter long. Males remain mobile throughout their two- to three-year life span and, like most other crabs, eventually develop into hard-shelled adults with prominent eyes and relatively stout chelipeds, or claws. But the males grow to no more than about 3/16 inch wide. Bristles on their second and third pairs of legs serve as an aid in swimming, and their flattened body, considerably thinner than that of the female, enables them to slip freely in and out of the narrow gape of mollusk shells as they shuttle from one temporary home to another. Females, on the other hand, generally find their way into the mantle cavity of a bivalve long before development is complete. There they mature, eventually attaining two or three times the width and thickness of the male but without the male's hard shell or bulbous claws, and with their eyes nearly concealed by a soft carapace. Poor swimmers, they remain within an individual mollusk, picking food particles off the gills or mucus strands of their filter-feeding host.

The freeloading habits of pea crabs are not news. Guillaume Rondelet's 1554 work *Libri de Piscibus Marinis* includes an illustration of a tiny crab, with somewhat exaggerated chelipeds, emerging from a mussel. (This drawing is reproduced at the top of the opposite page.) For most of the four and a half centuries since the publication of this treatise (and even today in some literature), the relationship between crab and mollusk has been considered commensal, with the crab benefiting by the association but neither hurting nor helping its host. The validity of this assumption is being reevaluated, however, and newer evidence suggests a less benign relationship. Compared with its nine-inch, clam-crushing relative the blue crab, this diminutive scavenger would hardly appear threatening, but its constant picking at the host's gills can result in considerable wear and tear over the years, and studies now show that the gill lesions frequently observed in occupied mollusks result in less efficient water filtration by the host. This compromised filtration, coupled with the crab's interception of food, can add up to significant metabolic costs for the host: both lower respiration rates and slower growth. Thus, while the crabs cause no immediately life-threatening damage, the female pea crab—unable to survive outside its host once it becomes established—is by all other measures a true parasite.

E.R. DEGGINGER; COLOR PIC, INC.

A pea crab at large

There may be another reason I failed in my initial attempts to locate this diminutive crab. Pea crabs are not found just anywhere. Whether due to the larvae's deliberate selection of a host or to improved survival under more favorable circumstances, pea crabs are found more often in larger mollusks, which filter a greater volume of seawater. They are also found more commonly in mollusks living beyond the lower tidal zone—that is, in areas where continuous submergence allows the host to remain open and filtering longer. In both cases, the advantage conferred is more food coming through the door. Had I been thinking like *Pinnotheres*, I might have experienced considerably greater success in my search.

Peter Marchand is a visiting scientist at the Carnegie Museum of Natural History's Powdermill Biological Station in Rector, Pennsylvania. *He wishes to thank Susan Geller, Pauline and Mike Severns, Jacques van Montfrans, Tommy Leggett, and David Beutel for going the extra mile to help with his quest.*

Whispers *in the* Canyon

Singing softly, Arizona's blue-throated hummingbirds go on the record.

By Kathryn Rusch

In the mountains of southern Arizona, a creek bubbles down a wooded canyon, heading to the desert a mile below. Painted redstarts hop along the water's edge calling to one another, and acorn woodpeckers screech from high in a giant sycamore tree. Listening carefully to the riparian symphony of birdsong, wind, and water, I begin to pick out some faint, clicky sounds. Then I locate their source. Just ten feet away, perched on a juniper twig, is a blue-throated hummingbird. A male, as evidenced by his iridescent throat patch, is facing the creek but repeatedly turns his head to scan the area. I watch as he lifts his bill slightly and again utters a soft series of whirs and clicks. He never opens his bill, but movements of his throat correlate with the barely audible song. After vocalizing for four seconds, the bird rests momentarily and repeats the song, continuing on and off in this way for about a minute. Then, in typical hummingbird fashion, the blue-throat departs at one notch south of light speed up the creek bed and out of sight. Fortunately, I have managed to catch his "whisper song" on tape.

Since 1995 my fellow ornithologist Millicent (Penny) Ficken and I have roamed the canyons of this region in spring and summer to document the songs of blue-throated hummingbirds. We work at two sites: the American Museum of Natural History's Southwestern Research Station in the Chiricahua Mountains, and Ramsey Canyon in the Huachuca Mountains. The study of birdsong is a rich and growing field. Because of their complex songs and specialized neural pathways for learning them, songbirds, or oscines, have been favored subjects of study among scientists. Over the past decade, however, researchers have begun to focus on the vocalizations of hummingbirds and other nonoscines, which belong to lineages of the avian family tree completely separate from that of the songbirds. Many songbirds, such as American robins and song sparrows, must learn their songs; some ethologists have started to look at the possible role of learning in nonoscines. Other researchers are investigating birds' vocal apparatus and areas of the brain involved in learning, to discover how song learning evolved separately in different avian lineages (see "Findings," October 2000). While some species of hummingbirds are known to sing—and Anna's, green violet-ear, and sparkling violet-ear hummingbirds appear to learn—we found that very little had been written about the sounds of blue-throated hummingbirds. Penny and I wanted to record the blue-throats in their natural habitat, analyze their vocalizations, and determine when and how the males of the species use the sounds to communicate. Along the way, we found out that the males were not the only blue-throated hummingbirds with something to say.

Blue-throated hummingbirds inhabit mountainous areas from southern Mexico to the southwestern United States. The blue-throats we study migrate relatively short distances from Mexico and begin to appear on their breeding grounds in southern Arizona in spring. Blue-throats hover at flowers such as bearded penstemon, mountain sage, and various types of agave to drink nectar, but their diet consists mainly of insects and spiders gleaned from vegetation and insects snatched midair while both birds and prey are on the wing. At times of the day when insects are less active,

STEVE AULSTON

A blue-throated hummingbird probes a penstemon flower for nectar, below. Populations of the birds spend summer along creeks and in wooded canyons of the Chiricahua Mountains of Arizona, opposite.

DAVID MUENCH

the birds will raid spider webs for ensnared arthropods. Like many other hummingbirds, male blue-throats defend a territory and fiercely repel intruders, particularly other males, by engaging in high-speed chases and physical combat that includes stabbing or "sword fighting" with their bills. In the populations we study, courtship may take place anytime from late April through early August. Males usually mate with more than one female and are totally uninvolved in the parental care of their offspring. Female blue-throats build their nests and care for the one or two young as a solo effort.

Small and speedy, hummingbirds do not lend themselves to easy observation, much less recording sessions. Although we follow color-coded birds marked with a small dot of nonpermanent paint, and we keep watch at feeders as well as creek sides, the blue-throats are often no more than beautiful colors in motion. But we do have advantages: blue-throats happen to be the biggest of the hummingbirds that breed in North America, and the males can often be found patrolling their linear territories along canyon creeks and singing from preferred perches.

Although it is a member of the largest hummingbird species to breed in the United States, a blue-throated hummingbird is dwarfed by the multiple blossoms of an agave flower cluster.

TOM VEZO

After recording our birds in the field, we head to the laboratory to begin the exacting task of turning our audio information into visual printouts. Because these vocalizations are mere whispers, many notes are emitted within seconds, and listening to the tapes does not enable us to discern all the components. We use a computer program to convert the tapes to a visual display called a sonogram, which, with a little practice, can easily be "read." The sonogram not only can reveal notes but can also show how groups of notes are repeated in a songlike pattern. After amassing a collection of sonograms, scientists can build a dictionary of sounds and search for patterns.

Our first step was to determine whether blue-throats do indeed produce a complex song. After generating many sonograms of our very first tape, we were surprised to find a high degree of complexity and variety in the notes of this particular male's vocalizations. Our second step was to collect

Males often sing before or after aggressive displays, fights, and chases. Females approach only singing males, never silent ones.

and analyze enough songs to determine whether all our male blue-throats sang a stereotyped song or whether the songs of individual birds varied substantially. Some species of songbirds have a simple repertoire. White-crowned sparrows, for example, all sing one basic song; at the other extreme are northern mockingbirds, which have rich repertoires. Each mockingbird compiles its own songbook by mimicking sounds—from other birds' songs to sirens—in its particular environment.

Our subsequent recordings of other blue-throats confirmed that notes were grouped. The groups were consistent both within an individual's vocalizations and across the population. Male blue-throats, then, do not appear to have distinct individual repertoires but sing the same tune. However, within the groups of notes were many different single notes that clearly demonstrated a large and complex acoustic dictionary. The pitch of the notes ranges from two to fourteen kilohertz—a wide spread of frequencies compared with those of songbirds, whose notes typically vary from about two to seven kilohertz. In addition, we found that the males did not randomly combine these groups of notes into songs but consistently put them in a particular order, which we refer to as syntax. We labeled the five groups we identified A, B, C, D, and E.

The peaks of the Huachuca and Chiricahua ranges can be considered "sky islands" rising out of a sea of desert. This geographical isolation allowed us to compare the songs of blue-throats living in ranges about one hundred miles apart. We found that blue-throated hummingbirds in both mountain ranges share the A, B, C, D, and E groups as well as

the same syntax. When we fine-tuned our analysis, however, we found consistent differences in the opening, or A, group of notes. Songs from the Chiricahua Mountains had a harsh tone absent in songs from the Huachucas. Other minor tonal idiosyncrasies appeared as well. So whisper songs do show slight geographical distinctions.

The songs we recorded during spring and early summer—the beginning of the breeding season—were more succinct and defined than the song of a male we recorded in August. That bird's song seemed to be less developed than the others. We believe this may have been due to his being a young bird. Could he have been "practicing" the song? Some birds, such as chickens, ducks, and gulls, are born knowing their vocalizations, while many songbirds and a few species of hummingbirds have a song that develops over time. The presence of poorly formed notes produced during a critical period when young birds practice singing may be a clue that learning is in progress. During this phase, vocalizations may become more distinct and timing may improve as the bird matures. Our taped song of the young male suggests that whisper songs may not be entirely preprogrammed and that learning may play a role in this species also.

Male songbirds may sing for four main reasons: to defend their territory, to attract a mate, to maintain the bond with the mate, and to induce egg laying in the female. To find out just when and why our non-songbirds were singing, we listened to and carefully watched blue-throats throughout their breeding cycles. We found that songs are sung in a variety of contexts—after foraging, before and after fights and chases, after preening, and after prolonged rest periods. Following spring migration, males arrive in the wooded canyons and begin staking out creek-side territories. Singing tends to be more frequent at this time and often precedes or follows fights, chases, and aggressive displays. One male, for example, would sing from a hidden perch in a dense juniper. If another male approached, the first would stop singing and chase the intruder, then promptly return to the perch and resume singing. One of our favorite singing males would perch on a laundry line at the midway point between the creek and a feeder. I recorded many of the great bouts of song he delivered in between his aggressive feeder patrols. We also noticed that females would approach only singing males, never silent ones. Perhaps the longer songs and longer bouts of singing we heard when sexual activity was at its peak give some indication to females that the singer is fit and healthy and will pass on quality genes.

SID AND SHIRLEY RUCKER; DRK PHOTO

Blue-throated hummingbirds enjoy nectar, but their main course usually consists of insects and spiders.

Blue-throats also voice a second type of sound that is simple, loud, and given from an exposed perch at dawn and dusk. It sounds like a series of "chips" and may be delivered in a single continuous bout lasting ten minutes or longer. These high-amplitude vocalizations, so different from the whispered quality of the song, may function as a long-distance advertisement of territory, carrying quite well above the din at the water's edge. The "chips" may correspond to the loud advertisement calls of songbirds, while blue-throat songs, like those of songbirds, serve to attract females and warn other males to stay away.

So why whisper, rather than belt out, a song? The answer may relate to habitat and to typical hummingbird displays. Like other birds, hummingbirds communicate through both auditory and vi-

sual signals. Many North American species of hummingbirds engage in dynamic aerial displays that play a role in territoriality and courtship. Shuttle flights—close-range, back-and-forth flights—are common and usually directed at a perched bird. Allen's hummingbird performs dive displays from heights of well over a hundred feet and at speeds of up to sixty miles per hour, while black-chinned, broad-tailed, Costa's, and others perform their own signature dive displays. These species, which do not sing complex songs, live in more open and variable habitats than blue-throats. Our whispering blue-throats do not engage in dives and shuttle flights. They live and reproduce in specialized habitats—deciduous streamside mountain canyons. Similarly, the white-eared hummingbird, which sings a complex song and does not display aerially, lives in a specific habitat of scrubby undergrowth in mountain woodlands.

In the case of the blue-throat, the water's edge can be a thick, verdant mix of shrubs and trees. The whisper songs may serve for close-range communication in dense creek-side habitats, where aerial maneuvers would be difficult to perform or hard for other birds to see. The sound of running water is a constant in the blue-throat's breeding habitat. Water sound frequencies are concentrated below 1 kilohertz, whereas the whisper song of blue-throats is concentrated at higher frequencies. The song also includes elements that seem to help it stand out against the sound of a gurgling creek. Studies of birds living near torrents in the Himalaya have shown that high-pitched songs are common against such a background of steady sound.

A male blue-throated hummingbird shows off his iridescent blue gorget and bright white tail highlights, below. Opposite: During the breeding season, males often patrol a linear territory along mountain streams and creeks.

BOB AND CLARA CALHOUN/CALHO; BRUCE COLEMAN INC.

Female song is rare in songbirds from temperate regions of the world and has not been reported in other hummingbirds. We found that during a brief interlude in the breeding cycle, female blue-throated hummingbirds produce their own complex whisper song, different from that of males. The territorial males are combative, quick to chase one another to acquire or defend nectar and other food sources, such as a succulent patch of penstemon in full bloom. If a female intrudes on a male's flower patch he will chase her away, but with less intensity. During the courtship period, the urgency to mate overcomes aggressiveness. Both male and female blue-throats use an array of sounds and postures to solicit company. Typically, a male will sing and a female ready to mate will approach, perch next to him, and join him in vocalizing. Although their songs are different, they overlap completely, an unusual phenomenon in the realm of avian communication.

Typically, a male will sing and a female ready to mate will approach, perch next to him, and join him in vocalizing.

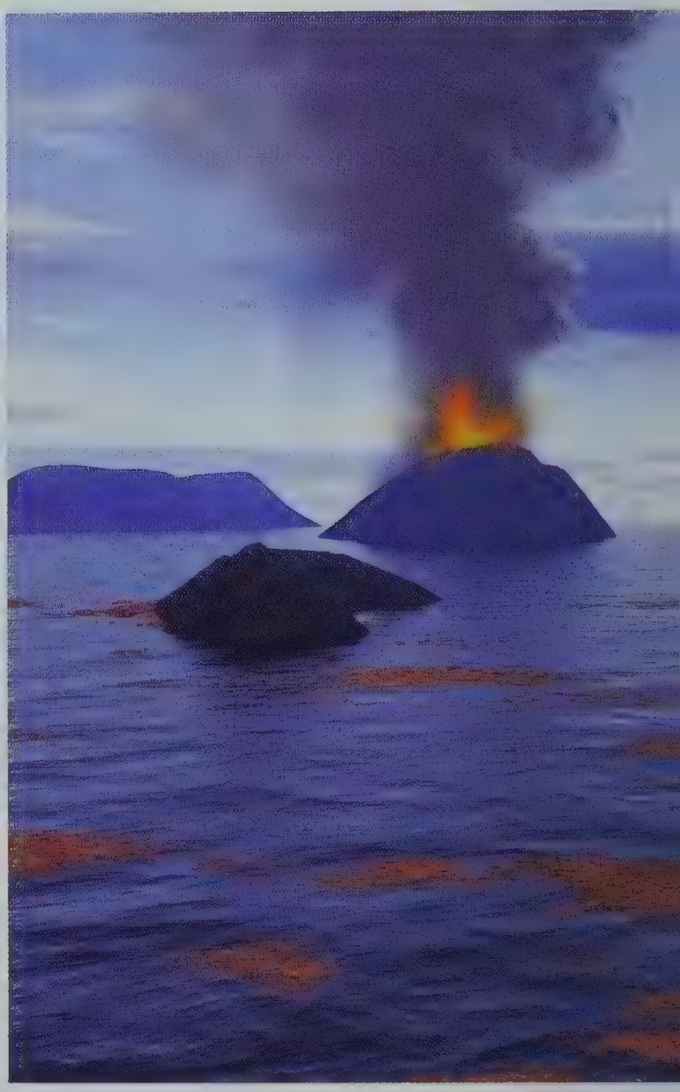
A female's song may indicate to a male that she is a potential mate and may help defuse his aggressiveness. Just prior to mating, the female constructs a tiny cup nest of moss, lichens, and the silk of spiders' webs. She then leaves the nest area in search of a male. During one to several days of whispering together, an unusually drawn out period of time for hummingbird sexual activity, the next generation is conceived. (In the few copulations we observed, the males also uttered a fragment of whisper song prior to copulation.) Our experiments have shown that the songs of female blue-throats do not travel very far through the environmental backdrop of thick vegetation, so these communications are up close and personal.

After about eighteen days' incubation, one or two chicks will hatch, fledge, and begin to whisper the blue-throat song. By late summer, the birds' breeding season, and our field season, will have wound down. The blue-throats, including the new generation, will head south to the mountains of Mexico, while Penny and I migrate back to Wisconsin. There, during the long winter, we will listen to our recordings of their song and plan for our rendezvous next spring. □

FEELING the BURN

Can plants and animals (including human beings) cope with increased exposure to the sun's ultraviolet rays?

By Jay Withgott

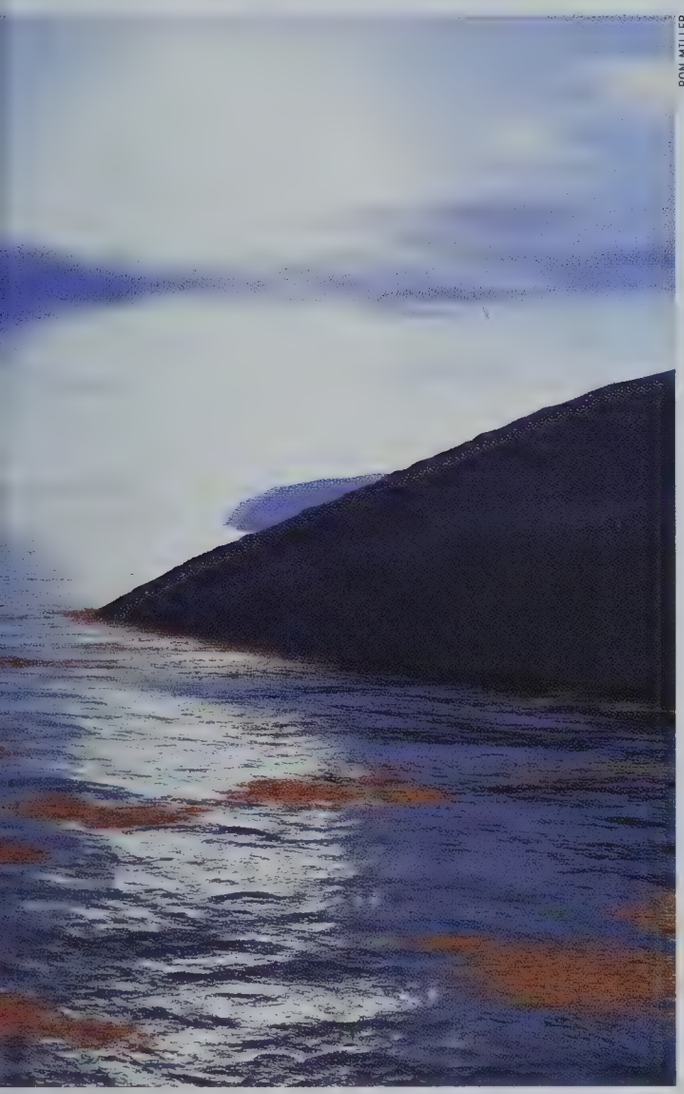


A shaft of sunlight is a double-edged sword. The sun powers life on earth, but its ultraviolet radiation—capable of bending DNA, RNA, and protein molecules into harmful shapes—poses a threat to life. We may love soaking up the rays, yet we also know enough to don hats, slather on sunscreen lotions, or head indoors to reduce the risk of skin cancer. Now that depletion of the ozone layer allows more ultraviolet light to reach us, we humans are learning to take extra precautions. But what about all the other organisms in the world, including plants, which can't retreat into the shade? Can they cope with increased exposure to ultraviolet light?

As it happens, this is not a new challenge. Two billion years ago, when life inhabited only the seas, relatively little oxygen and ozone circulated in the atmosphere. These gases began to accumulate only when organisms capable of photosynthesis evolved. The first such organisms were the one-celled cyanobacteria (and members of this group are still with us today). They churned out oxygen (O_2). Ozone (O_3) was created when ultraviolet light bombarded oxygen molecules and knocked some of them apart, allowing lone oxygen atoms to latch onto other oxygen molecules. Eventually a thin layer of ozone formed in the stratosphere.

The ozone layer resists penetration by ultraviolet light; hence the alarm generated by the ozone hole over Antarctica. This calamity is apparently the result of human pollution of the atmosphere. Such depletions may have been "geologically quite common," however, suggests Charles Cockell, of the British Antarctic Survey. He reasons that comet or meteorite impacts, intense volcanism, and nearby supernovas—catastrophic events capable of causing mass extinctions such as those evident in the fossil record—could have led to massive ozone loss. The climatic "winter" believed to have been triggered by such catastrophes, Cockell argues, would often have been followed by an "ultraviolet spring," which could have helped finish off organisms under stress that survived the initial event.

Extraordinary episodes apart, the ozone layer has never completely sheltered life-forms from ultraviolet light, so organisms have evolved ways to reduce the damaging effects of exposure. Lynn



RON MILLER

Earth two billion years ago, as envisioned in an artist's rendering: The land had yet to be colonized, and the oceans contained only microscopic organisms, among them the cyanobacteria, which formed mats both on the water's surface and in intertidal zones. Pioneers in photosynthesis, cyanobacteria were responsible for adding oxygen—and ultimately ozone—to the mix of atmospheric gases.

Rothschild, of NASA's Ames Research Center, suggests we may discover that ultraviolet radiation played a creative role in several evolutionary milestones. She speculates that it spurred the appearance of the first eukaryotes (organisms in which the cell has a defined nucleus), prompted organisms from the sea to colonize the land, and helped drive the evolution of DNA repair processes that may underlie the origin of sexual reproduction.

Ultraviolet light (UV) is part of the spectrum of electromagnetic radiation with wavelengths too short to be perceived by human vision (X rays and gamma rays have still shorter wavelengths). Biologists divide it into three types, based on the radiation's biological effects. A great deal of UV-A, with wave lengths of 400–315 nm (nanometers, or billionths of a meter), reaches the earth's surface, but it poses little danger to life. UV-B (315–280 nm) causes biological damage and reaches the surface in varying amounts (1 to 10 percent gets through the atmosphere). UV-C (280–100 nm) is the most damaging of all but fails to penetrate the upper atmosphere even where the ozone layer is weakened. Thus biologists, as well as knowledgeable sunbathers, focus their attention on UV-B.

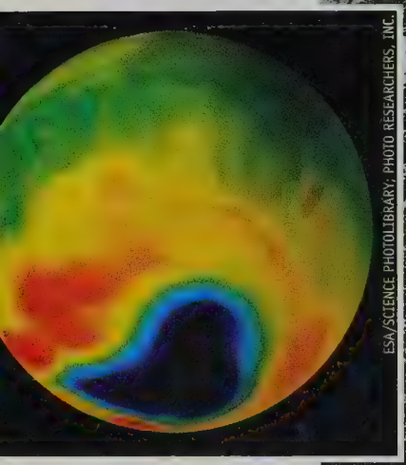
Three decades ago, research on the biological effects of ultraviolet light was stimulated by sugges-

Surges in ultraviolet radiation may have had a role in mass extinctions.

tions that supersonic transport aircraft might destroy the ozone layer. The discovery of the Antarctic ozone hole, however, was the real wake-up call. Many scientists warned that increased UV-B levels were not only a threat to species but might also disrupt ecosystems. One report on phytoplankton (algae and other drifting plant life) in Antarctic waters showed a 6 to 12 percent decrease in their productivity—that is, conversion of energy into biological mass through photosynthesis. This boded ill, because phytoplankton are considered the base of the marine food web, ultimately supporting such high-level consumers as fish, squid, and whales.

Fortunately, a few scientists had been laying the groundwork for studies on the biological impact of ultraviolet radiation. One was Martyn Caldwell, now at Utah State University, who as a graduate student back in the 1960s elected to study alpine plants and ultraviolet radiation. He and other early researchers investigated UV-B's potential consequences for plants and also how organisms were

Antarctica is home to only two flowering plants, pearlwort (inset, top right) and hairgrass (bottom right). Both species have had to compensate for the recent depletion—due to pollutants such as chlorofluorocarbons (CFCs)—of stratospheric ozone, which shields the earth from ultraviolet radiation.



ESA/SCIENCE PHOTOLIBRARY, PHOTO RESEARCHERS, INC.

Above: The ozone hole over Antarctica was mapped by satellite in October 1995; black indicates the lowest ozone concentration, blue to green indicates more, and red to yellow, the most.

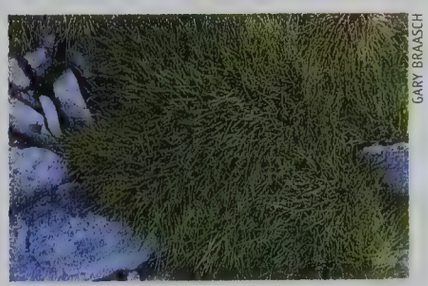
coping with ultraviolet light. Come the ozone-hole scare, researchers hit the ground running, measuring ultraviolet light's effects on a range of species through laboratory and field experiments that either increased or filtered out UV-B.

In Antarctica, marine biologists measured productivity in the lush "meadows" of phytoplankton at sea, while other biologists, such as Thomas (Tad) Day, of Arizona State University, Tempe, examined plants on dry land. Botanical identification is child's play on the Antarctic continent, which has only two species of flowering plants—a tiny grass and a pincushion-shaped plant that in the harsh climate takes half a century to reach the size of a softball. Day has found that under increased UV exposure, these plants produce smaller, thicker leaves and stock them with extra photosynthetic pigments and other chemicals. For every unit of surface area, says Day, "your construction costs are higher," and these costs may accumulate over time. In a four-year experiment, Day found that the plants were more adversely affected each year.

At the other end of the world, in Sweden, researchers at the Abisko Scientific Research Station pioneered the study of UV effects near the Arctic Circle. Their field experiments have shown that UV exposure can reduce nitrogen fixation (the incorporation of atmospheric nitrogen into ammonia), a process that makes nitrogen organically accessible. They also found that such exposure can

GARY BRAASCH

GARY BRAASCH


GARY BRAASCH

make shrubs more vulnerable to early frosts and that it has mixed effects on plant-litter decomposition (UV-B breaks down litter photochemically, but it also kills bacteria and fungi that aid decomposition). Unlike the Antarctic researchers, however, the Abisko scientists found that some plants they observed did acclimatize to increased UV exposure.

Other scientists were finding that UV-B stimulates the movement of transposons (sequences of nucleotides that can change position on a chromosome) within plant genomes. For example, by irradiating maize pollen, Stanford University's Virginia Walbot induced rampant relocation of these "jumping genes." This type of genetic shuffling may have unpredictable, often deleterious effects.

Meanwhile, researchers studying UV exposure in animals were learning that it causes everything from developmental problems in fish and retinal damage in frogs to outright death in zooplankton (drifting marine animals, usually of microscopic size). Ultraviolet light has been implicated as one cause of a global decline in amphibians and might also play a role in declines observed in many salmon populations around the world.

Plants have chemical sunscreens that intercept ultraviolet light.

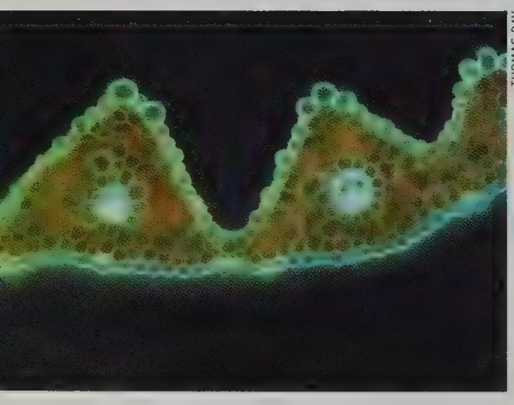
As they tabulate the effects of UV exposure, scientists have also learned more about the defenses that organisms erect against ultraviolet light. Many have chemical compounds that intercept incoming radiation before it reaches cell nuclei. In plants, flavonoids and other phenolic compounds (pigments that in many cases color plant parts) absorb UV-B. In many animals, pigments such as melanin serve to block ultraviolet light; a number of amphibians, for instance, produce eggs equipped with melanin. And in many microorganisms as well as in larger creatures, chemicals called mycosporine-like amino acids (MAAs) also play a role as natural sunscreens.

Animals cannot synthesize MAAs but have found ways to obtain them from the plants, fungi, and microbes that can. J. Malcolm Shick, of the University of Maine, and his colleagues have found that corals acquire MAAs from the one-celled dinoflagellates that live inside them as mutualists, swapping food and sunscreens for a place to live. They've also shown that sea urchins and sea cucumbers obtain MAAs by eating algae and cyanobacteria. Deneb Karentz, of the University of San Francisco, has determined that the urchins concentrate these MAAs in their eggs; because the eggs are released into surface waters, they need the protection more than the bottom-hugging adults do, she says.

Often, exposure to sunlight stimulates production of these radiation-intercepting compounds. Extra melanin is deployed in human skin exposed to the sun; this protective response of tanning also occurs in some other mammals and even in some sharks. Production of MAAs and flavonoids may require exposure to UV-A light. But biologists don't know whether organisms evolved the capacity to produce these kinds of chemicals specifically in response to the hazards of ultraviolet radiation. Plant phenolic compounds, for example, play other roles, such as staving off insect attacks. MAAs, by contrast, are not known to serve any other function.

Some ultraviolet radiation is bound to sneak past even the best sunscreens, however. The task of repairing the DNA damage is the responsibility of enzymes—such as photolyase, which is found in nearly all organisms. The chemical armies within plants and animals have to fight on another front, too, for ultraviolet light also releases free radicals, which oxidize many biological molecules, including DNA. In plants, carotenoid pigments such as anthocyanins often help tackle these aggressors.

Organisms vary in their defensive strategies. The microscopic invertebrates known as rotifers, for instance, load up with sunscreens but do little repair, whereas fish eggs and larvae have very high repair rates. One mundane yet effective defense is physical protection: fur, feathers, shells, and scales. Tunicates (sea squirts and similar small marine chordates) add layers of extra cells around their eggs and embryos, Stanford's David Epel has found. Some amphibians and fish lay eggs in clusters, with the outer ones protecting the inner ones. Adolfo Marco, of Seville's Doñana Biological Station, and his colleagues have studied a salamander that wraps its eggs in leaves. And ancient cyanobacteria often built up layered structures known as stromatolites—as do their modern descendants—in which the individuals on top bear the brunt of solar radiation. Although some of these protective measures may have evolved in response to other environmental factors, they also serve as effective sun shields.



THOMAS DAY

A cross section of an Antarctic hairgrass leaf—photographed with a technique that causes its normally colorless sunscreen compounds to fluoresce blue-green—shows that the compounds are concentrated in the outer layer of cells. These sunscreens protect inner tissue that performs photosynthesis; the chlorophyll in this tissue glows red.

Of course, mobile organisms can simply move out of the way of ultraviolet light by seeking shady habitats or by becoming nocturnal. In the daytime, many planktonic organisms, including tiny aquatic crustaceans called *Daphnia,* move downward in the water to depths not reached by most ultraviolet light. They then move upward at night. Yellow perch, which normally lay their eggs in shallows, seek deeper water when exposure to ultraviolet light becomes intense. Many marine invertebrates spawn at night, when their delicate eggs and sperm will not be scorched by ultraviolet light. Again, it is difficult to determine whether or not these various kinds of behavior evolved primarily because they protect against ultraviolet light.

Given all this, one might expect to find a correlation between the amount of ultraviolet radiation to which a particular kind of organism is exposed and its defense capabilities. Most biologists hesitate to declare that such a tight pattern exists, but some findings are suggestive. Comparing various frog, toad, and salamander species, Oregon State University's Andrew Blaustein has found that those species whose eggs are normally subject to the highest UV exposure show the greatest photolyase activity. Martyn Caldwell, surveying across latitudinal and altitudinal gradients from Alaska to the equatorial Andes, discovered that plants tend to filter out ultraviolet light most in low latitudes and high altitudes, where it is most intense. Karentz has found that sea urchins living in intertidal zones have higher MAA levels than those inhabiting deeper water—a pattern that Shick and others have also detected with corals.

Many sea animals spawn at night, when eggs and sperm can't be scorched.

The correlation closest to home, though, concerns differences in human skin coloration, a phenomenon whose evolutionary significance has long been debated. Last year, anthropologists Nina Jablonski and George Chaplin, of the California Academy of Sciences, created a stir when they published an exhaustive account showing that indigenous human skin coloration varies across the globe in relation to UV-B intensity, as determined by NASA's measurements of the variation in ultraviolet radiation reaching different areas of the earth's surface. They also offered an explanation: in equatorial climes, the melanin in darkly pigmented skin protects against damage, while in regions closer to the Poles, which receive less sunlight, melanin has

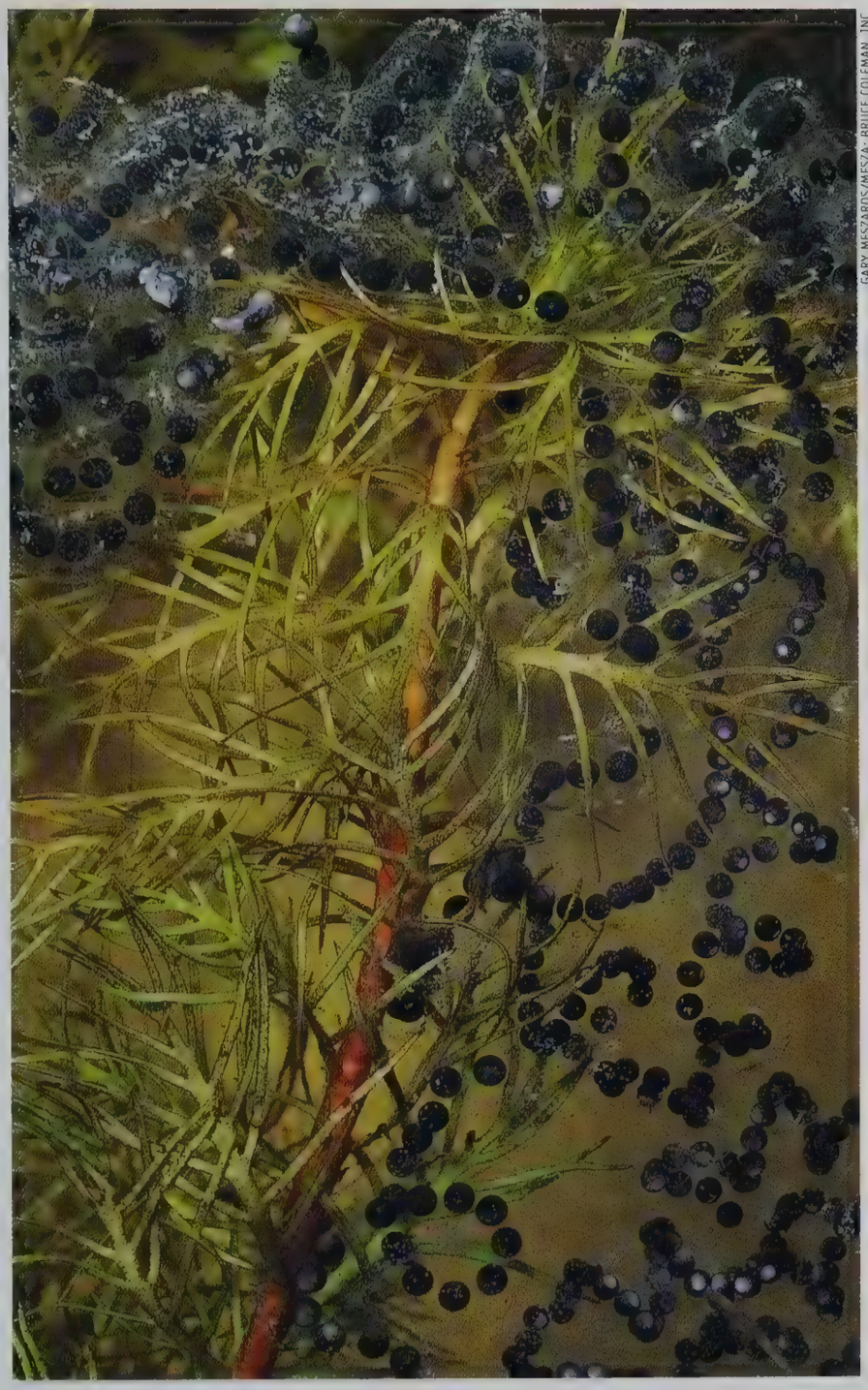
been reduced, assuring the penetration of sufficient light for vitamin D synthesis. They further maintain that equatorial peoples did not evolve dark skin because it affords protection against skin cancer, since cancer does not usually kill people during their reproductive years. Rather, they argue, the chief threat of ultraviolet radiation is destruction of folate, a metabolite essential for human embryonic development; another very serious threat is damage to sweat glands, which are so essential for thermoregulation in humans.

From melanin to photolyase, the same defense strategies are found in many different species, suggesting that these defenses originated in distant ancestors many millions—even billions—of years ago. Ancient cyanobacteria certainly succeeded in surviving UV exposure somehow; modern cyanobacteria show substantial levels of MAAs and other sunscreens. "The thing that is striking to me is the extent to which many organisms have already addressed the UV issue," comments Lehigh University's Craig Williamson.

Does that mean we humans should worry only about our own exposure and let the rest of nature take care of itself? Well, not exactly. We must also be concerned about the possible loss of other species and the condition of the biosphere on which we depend. Thankfully, the worst-case scenarios envisioned a decade ago—such as the collapse of the Antarctic food web—have not come to pass. But a slew of studies have shown how the impact of ultraviolet light extends beyond individual organisms, altering the balance of species in habitats and ecosystems.

Much of this work was inspired by a 1994 study by Max Bothwell and his students Darren Sherbot and Colleen Pollock, of Environment Canada. They demonstrated that, unexpectedly, stream algae benefited overall from ultraviolet light; the radiation hurt insect larvae that fed on the algae more than it hurt the algae themselves. In ecology, the enemy of your enemy can be your friend.

"When you get into the ecosystem-level responses, things get interesting," says Nigel Paul, of Lancaster University. "They're more complex and less predictable." Paul has found that with increased UV exposure, pea plants become more resistant to insect pests—because the leaves suffer a decrease in nitrogen content, making them less nutritious and less attractive, and because production of phenolic compounds increases, also discouraging insect appetites. Similarly, Caldwell's group, working in southern Argentina, has determined that ultraviolet



GARY MESZAROS/MESZA; BRUCE COLEMAN, INC.

Left: Eggs of the American toad contain melanin, which helps protect them from overexposure to ultraviolet light. Southern Europe's marbled newt, below, wraps its eggs in leaves. Experiments have shown that this practice helps the eggs survive UV exposure; it may also protect them from other hazards, such as predators.

DANIEL HEUCLIN; NHPA

light reduces insects' taste for plants, perhaps by causing an increase in phenolic compounds.

In contrast, researchers at Sweden's Abisko station have found that increased UV exposure appears to threaten trees in northern forests. While mountain birch produced sunscreens that made its foliage hard to digest for caterpillars of the autumn moth, the caterpillars simply ate more leaves to compensate for their lowered nutrition. In addition, ultraviolet light seemed to make the caterpillars better able to fight off harm from the larvae of parasitic wasps, which normally help keep the caterpillar population in check.

Folate, crucial to a human embryo's development, is destroyed by UV-B.

Large-scale ecological effects are hard to predict not only because they involve multiple species but also because ultraviolet light may interact with other factors. Global warming and acid rain, for instance, reduce the amounts of organic matter in Canadian lakes, allowing ultraviolet light to penetrate the water more deeply. Joseph Kiesecker, of Pennsylvania State University, Blaustein, and Lisa Belden, of Oregon State University, have shown that intensified El Niño cycles periodically lower water levels in lakes and ponds, exposing amphibian eggs to more ultraviolet light and thereby promoting their fatal infection by fungal pathogens. The likelihood of such unanticipated synergistic effects is one reason researchers urge us to remain concerned about ozone depletion.

And although the impacts detected so far do not seem drastic, we may be unaware that profound changes have already occurred. Karentz points out that Antarctic phytoplankton are generally single-celled organisms with life spans of hours to days. "Anything that could not have survived those first few ozone-hole events is gone now," she says. Caldwell echoes her concern: "Maybe we're looking at a system that's already been altered, and no one studied it previously to have a before-and-after comparison. Perhaps we're just too late." □

GWEN GOODMAN-LOWE

a shallow seawater pond in Hawaii exhibit tanning. The shark at left was sheltered from ultraviolet rays.

JEAN-PAUL FERRERO- AUSCAPE

On Bondi Beach in Sydney, Australia, right, sunbathers cultivate their melanin, whose distribution and quantity in the skin changes with exposure to ultraviolet light. Variations in human skin color and in the tanning response probably result from the evolution of ancestral populations at different latitudes and under different climatic conditions. Below: Baby hammerhead sharks raised in

Besides sipping flower nectar, these flighty insects dine on sweat, tears, and slug slime.

BUTTERFLY BUFFET

By Phil Schappert

Most people associate butterflies with flowers. Flight requires a great expenditure of energy, and these insects get most of the calories they need to control their wing muscles from the sugar in flower nectar. The best flowers for butterflies produce nectar with a 20 to 25 percent sugar content and store it in chambers that can be easily penetrated by the insect's uncoiled proboscis. Suitable blossoms also present a "landing pad" on which the butterfly can alight. Among the favorites are asters and daisies, milkweeds, mustards, mints, peas, and vervains.

While flower nectar forms the bulk of most butterflies' diets, these insects actively pursue many other kinds of food (some species do not utilize nectar at all). In addition to finding the sugars, salts, nitrogen, and amino acids they need to survive, they must also consume certain chemicals used for making sex attractants. Tree sap, wet soil, flower pollen, and dead plants are part of the motley assortment of foods commonly sought by butterflies, but the full list is far longer. Butterflies are supreme opportunists, and their expanded menu may also include rotting fruits, vegetables, and mushrooms, as well as carrion, owl pellets, mammal dung, urine, bird droppings, slug slime, tears, sweat, and other animal secretions. These items do not readily come to mind when we think of colorful, frolicking butterflies, yet they are common alternatives to flower nectar.

Butterflies seek out such fare to obtain additional compounds they need to function as adults; the plants they ate when they were caterpillars had low levels of some crucial compounds. For example, plant tissues have relatively little salt, which is essential for all animals. Like deer and other creatures that eat only plants, butterflies must find salt in other places, such as natural mineral deposits. Similarly, most plants contain little nitrogen, so the caterpillars that feed on them—and the adult butterflies those larvae become—operate on a nitrogen deficit. Male and female butterflies, however, use different sources to correct these deficits.

Butterflies, like many other animals, have evolved the practice of providing "nuptial gifts." During copulation, the male transfers a spermatophore—a packet of nutrients, salts, and sperm—to the female. This is no small gift. A spermatophore can weigh as much as half the male butterfly's own weight, and the female may depend on it for the materials necessary to provision her eggs. Consequently, she can save the time she would otherwise spend searching for these compounds and concentrate her efforts on locating host plants for her eggs.

The male, on the other hand, must seek out sources of the chemical compounds essential to the nuptial gift, so he directs his activities in different ways and to different places than the female does. This partly explains why males constitute the vast majority of butterflies clustering at salty or urine-soaked ground, colloquially known as puddle clubs. Urine is easy to find by its strong odor—and it's a veritable cocktail of nitrogenous waste, amino acids, salts, and excreted sugars. To an unmated male butterfly, puddle clubs are the equivalent of fine dining. And if a puddle gets a four-star rating, feces garner twice that, and carrion even more. □

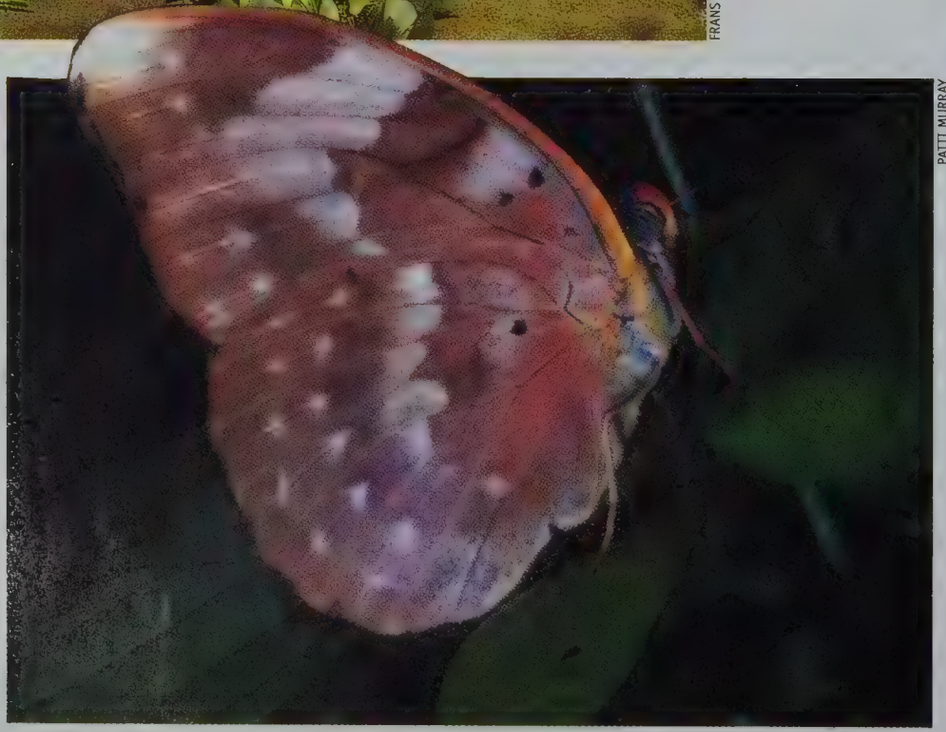
Male queen butterflies (*Danaus gilippus*) compete for access to the dry head of a flossflower in southern Texas. Having moistened the flower's surface with regurgitated fluids, they can imbibe dissolved chemicals, which they use for making sex pheromones.

DURRELL D. KAPAN

The salts and nitrogenous compounds in bird droppings provide nourishment for many insects, including a tropical skipper (Hesperiidae) at Tinalandia Reserve in Ecuador.

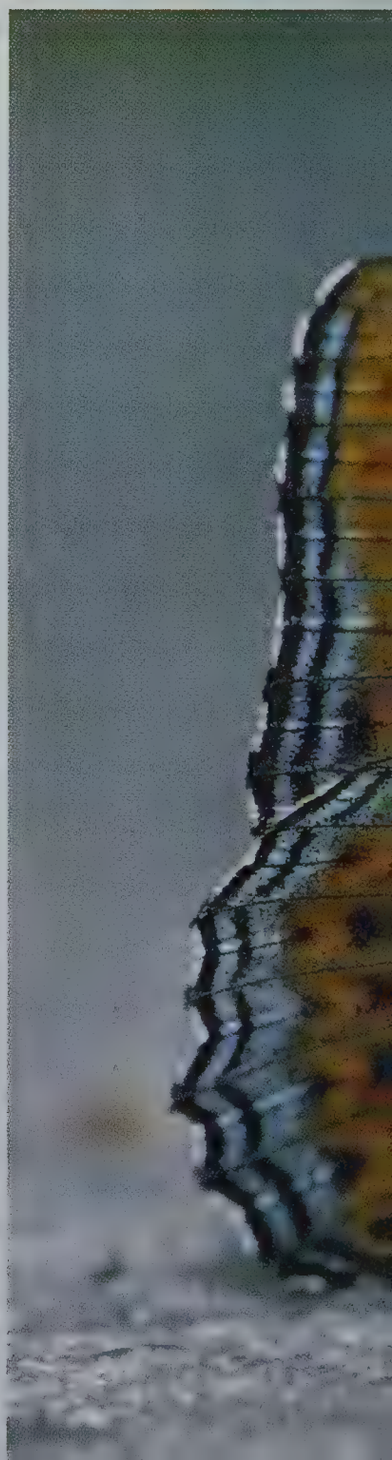
FRANS LANTING; MINDEN PICTURES

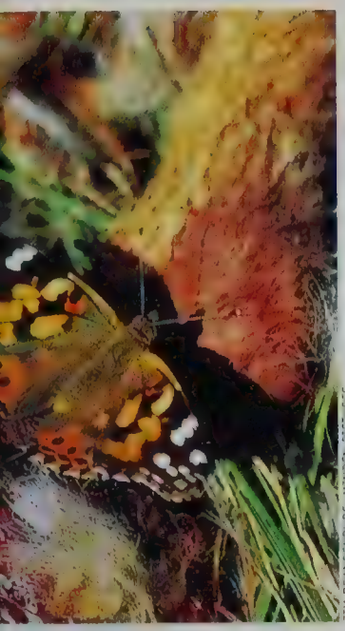
In Peru, a congregation of various pierid and other butterflies sip mineral salts from damp sand.



PATTI MURRAY

In Kenya, a gold-banded forester butterfly *(Euphaedra neophron)* feeds on a slime trail that a slug has left on a leaf.





JIM BRANDENBURG; MINDEN PICTURES

A painted lady *(Vanessa cardui)* feeds on the nutrient-rich carcass of a swift fox in western South Dakota.

RICHARD TANNER

Two *Morpho peleides* dine on fallen fruit in Costa Rica. Natural fermentation provides an alternative source of the energy-rich sugars they require.

MARIO MAIER; GERMANY

A poplar admiral *(Limenitis populi)*, left, shares a piece of fox dung with a scarce fritillary *(Euphydryas maturna)* in the countryside of southern Germany.

The CONDOR and the

An Andean spectacle

"We did not get the pay we were promised," complains José Quispe. He and twenty other men endured two weeks without shelter in the cold, arid Peruvian plateau, subsisting on meager rations, in order to capture a condor for the big fiesta in the village of Cotabambas. Hired by the district governor and district mayor, Quispe (a pseudonym) and his companions—all of whom are Indians who speak more Quechua than Spanish—fulfilled their end of the bargain. The job required hiking 3,000 feet up from their Andean village (elevation 11,000 feet), killing an old horse brought as bait, and waiting until the rotting carcass finally attracted the scavenging bird.

The capture itself required considerable exertion. The bait was placed at the bottom of a hollow, and the men spaced themselves around the rim. After the condor landed to feed, a signal was given and the men swooped down from all sides, shouting and swinging their lassos and ponchos. A condor cannot easily take flight from the ground without a running start and thus rarely escapes if its hunters are quick. After wrapping their quarry in a poncho, the men carried it down to Cotabambas in time for the village's national Independence Day festivities, held during the last five days of July.

As farmers who subsist by growing corn, potatoes, and wheat and by breeding a few sheep and cows, the men welcome odd jobs. A dollar a day is average pay when a man works in the village for one of the more affluent mestizos, bilingual residents of mixed European and indigenous ancestry. Three dollars a day was promised for catching the condor, so the job sounded very attractive. But the men have been told that, at least for now, there isn't enough money to go around. Quispe says some of them have received two dollars, others one dollar, and a few nothing at all.

Cotabambas (population 1,300) lies about thirty-five miles (as the condor flies) west of Cuzco, which in former times was the capital city of the

Schoolboys prepare for the national Independence Day parade in Cotabambas, Peru. Behind them, a statue of a condor riding a bull portrays what will be the highlight of the festivities.

BULL

Story by ***André Affentranger*** *~ Photographs by* ***Ernesto Bazan;*** GETTY IMAGES

less—and more—than meets the eye.

Quechua-speaking Inca. Cuzco is five to nine hours away by bus or truck, and most of the villages near Cotabambas can be reached only on foot or horseback. The community's one telephone, in Ludmila Ortiz de Zevallos's grocery and variety store, has been there just a couple of years. Yet at the end of July, movie teams, photographers, and journalists from all over the world, together with students and professors from the anthropology and

The hunters had to wait until a horse carcass attracted the scavenging bird.

tourism departments of Cuzco's National University of San Antonio Abad, converge on the village for the events marking Peru's independence from Spain. "These are the only days when Cotabambas wakes up from its lethargy," comments middle-school principal Julian Baez.

The crush is the result of the *toro pujllay* (bull games), the bullfights that take place during the two days following Independence Day, July 28. The setting is a grassy village square that is turned into an arena by blocking off the entrances with tree trunks. No bulls are killed during the bullfights; instead, toreros show their bravery by closely engaging the animals with their ponchos, jackets, or homemade capes. These bulls can be quite wild, since they usually range free in the mountains. Prizes such as sheep

At the rim of a hollow high in the Andes, above left, men lie in wait for a condor to take the bait. Above right, the captured bird is carried down to the village. Right: The man in charge of the expedition (center, wearing a poncho) presents the animal to the authorities responsible for organizing the village festivities.

and beer encourage the toreros to take risks. The climactic event, however, consists of tying the captive condor by its feet onto the back of a bull. Crazed by the flutter of wings and the bird's attempts (even though its beak is tied shut) to bite his back, the bull rages for two or three minutes, jumping impressively around the arena to enthusiastic applause. The following day, the condor is released.

Movies and news reports generally represent the spectacle as a metaphor for the struggle between the indigenous population (the condor) and the Spanish conquerors (the bull) or, in the same vein, as symbolic revenge on the part of the Indians for the injustices they had to suffer under Spanish domination. This is the explanation offered by the mestizos, the people most apt to be interviewed by journalists, who stay in the village just a few days. And this interpretation, which so appeals to readers and viewers in the United States, Europe, and Japan, may have acquired some validity. But it isn't the one given by the Quechua farmers, who enrich the fiesta by singing and dancing until the last drop of alcohol is consumed.

Although not a native animal, the bull has, after five centuries, become fully integrated into the indigenous world. The *toro pujllay*—with or without the condor—is a fixture of most celebrations in the Andes of southern Peru, and to most Indians, the blood shed by toreros injured in the event is in part an offering to Mama Pacha, or Mother Earth. As far as the region's farmers are concerned, the inclusion of the condor is simply another tradition, an added feature that makes the celebration all the more exciting and attractive for the audience.

Above: Drinking is integral to the celebration, which continues for five days. Right: A bull corners a torero, whose goal is to closely engage the animal, not to kill it. Prizes are offered to encourage bravery.

"Even before me, my uncle and great-uncle caught condors," says Lucio Mantilla (a pseudonym), a Quechua farmer who has led condor-catching expeditions since 1956. "From time to time, the authorities in Cotabambas would ask them to bring a condor for either Independence Day or the day of the patron saint, so that the bull would become wilder and the bullfight more interesting, earning more prestige for the sponsors." But the custom may not be terribly old: there seems to have been no indigenous tradition of capturing live condors for ceremonial purposes, and the earliest account of a condor bullfight anywhere in the Andes appears to date from the second half of the eighteenth century.

"These are the only days when Cotabambas wakes up from its lethargy."

Nowadays the condor bullfight in Cotabambas occurs almost exclusively during the July festivities, but at one time it took place around December 8, the day of the Virgin of the Immaculate Conception, the village's patron saint. Organization and funding of the fiestas was undertaken by one or two sponsors, known as *dueños del cargo* ("masters of the obligation"). Normally these were great landholders who underwrote the expenses to enhance their own prestige and to show piety toward the saint.

Such sponsorship is no longer possible. "After the agrarian reform of 1969," explains Wilbert Chaco (a pseudonym), a teacher in the district, "nobody had the funds needed to organize such celebrations anymore. On top of this came the resistance of the Augustine monks, who did all they could to discourage such excessive occasions." In the 1960s, after an absence of 150 years, the Augustines had returned to the village and restored the local church, reestablishing a Catholic priestly presence. On religious grounds, they opposed the association of the bullfights and other spectacles with the patron saint. The switch to July occurred more for economic and political reasons, however, and during the past few years, in fact, a condor bullfight has been reintroduced in December.

Most of the responsibility for organizing the event now lies with the district governor and the district mayor, but the financial burden is borne chiefly by their political representatives in each of the eight participating villages—the deputy governor and the mayor's agent. Both posts are held by indigenous people chosen locally. Each representa-

Below: Young musicians rehearse for the July 28 parade commemorating Peru's independence from Spain.

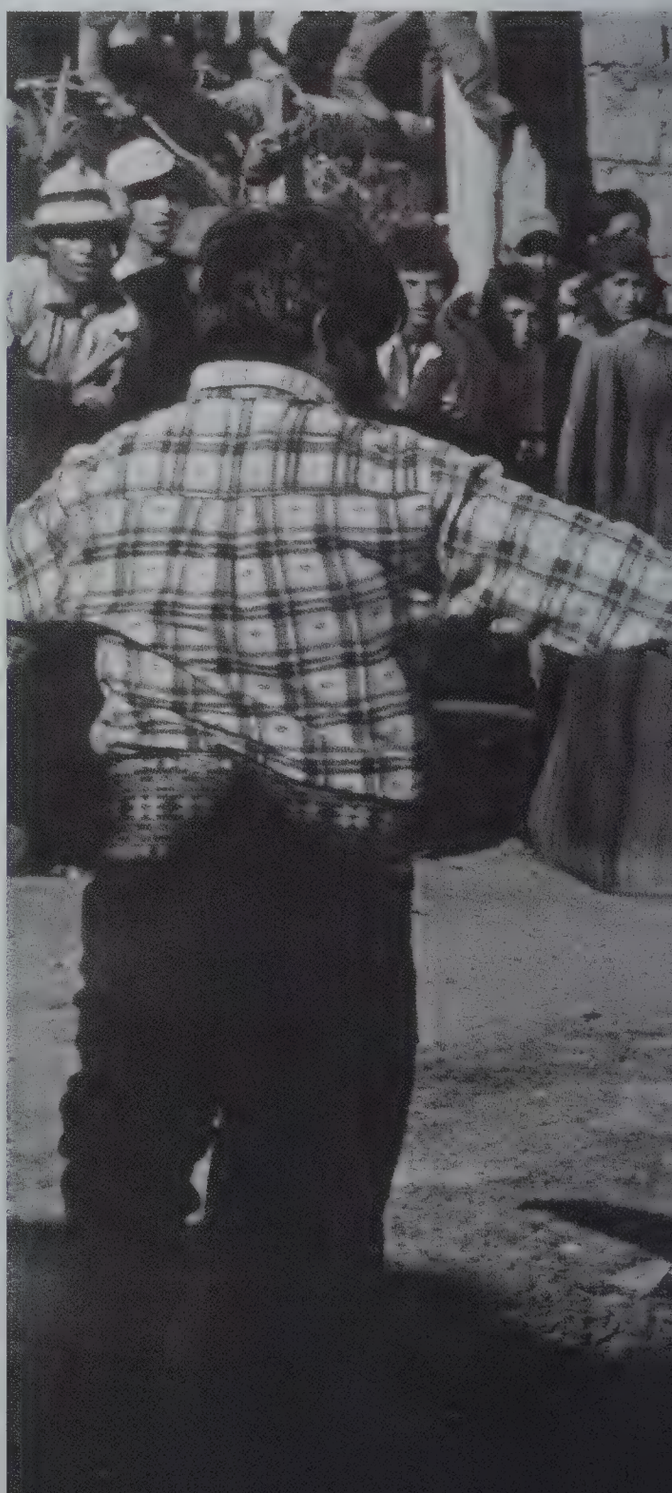
tive is obliged to provide a band, abundant supplies of maize beer and alcohol, food, two bulls for the bullfight, and prizes for the best toreros.

While those in the region who hold important political and educational positions come from the former landholding families, the indigenous officials are not nearly so well off. A representative's Independence Day expenditures (about $600) are so high that nowadays hardly anybody willingly shoulders the office. "The duties for July 28 are very hard on us, as we are already poor and this fiesta makes us even poorer," says the deputy governor in one of the participating communities. "But the mayor and the governor tell us that we are responsible for carrying on these old traditions from the time of the Inca and that we have to fulfill our obligation, as our fathers did before us."

The condor bullfight is so extraordinary an event that a number of people have been capitalizing on it for quite a while. According to Wilbert Chaco, the commercialization of the condor catch

was started in the 1960s by an important local landowner and politician. "At the beginning," says Chaco, "it was by exacting a consideration for the bird from those obligated to sponsor the fiesta, then later by selling permission to witness the condor capture to film teams and journalists."

Now it is almost impossible for outsiders—including Ernesto Bazan, whose photographs accompany this story—to document the condor-catching expedition without making informal payments to some of the principals. These include the man (typically a politically well connected mestizo) who organizes the expedition and who usually accompanies it on horseback. And because journalists from outside the area interact most frequently and readily with this individual, he ends up figuring prominently in their documentaries and news videos.



The condor is presented to the public, left, on the first of two days of bullfighting. Above and right: Tied to a bull by its feet, the condor excites its mount, which bounds around the arena for several electrifying minutes. To ensure that the custom will be allowed to continue, as well as out of respect for the mountain spirits, the villagers protect the condor from harm during its days of captivity.

While regrettable from some points of view, this commercialization is one of the principal reasons the tradition has been able to survive. Since 1970, Peru's Ministry of Agriculture has forbidden the capturing of condors except for "scientific or cultural purposes." The fame that the village has achieved through films and press coverage has made Cotabambas one of the few communities that can probably count on getting an informal cultural exemption. Some other villages have given up the tradition, substituting something more like a Spanish *corrida;* others now tie a dog or a duck instead of a condor onto the bull. While in Cotabambas the bulls are never killed and the condor is carefully protected and well fed with meat, beer, and wine, the animals used in these other villages are not likely to be treated with the same care.

Solicitude for the condor has a practical motivation, because if the bird were to be accidentally killed or injured, it might mean an end to a popular and, for some, lucrative event. For José Quispe and the other Quechua farmers whose job it is to capture the bird, however, the sentiments run deeper. To them, the huge Andean condor is a messenger of the Apus, the sacred mountains. According to a widespread belief, anyone who harms a condor in any way may be struck by lightning.

The men of the condor-catching party follow certain ritual procedures as they pursue their goal. The old horse brought as bait is killed by strangling it with ropes as it faces the sunrise. And during their mission, the hunters carry out ceremonies directed to the holy mountains and to Mother Earth so that a condor will be attracted to the carcass. Among the indispensable offerings for these rituals are mussels, snail shells, corn husks and kernels, incense, coca leaves, and llama fat.

On July 31, the last day of the festivities, the condor is carried to a steep hillside where it can be safely released. Offerings are made once again to the mountains and Mother Earth, thanking them for the condor and asking them to protect it on its way home. If many film teams and journalists are present, the mestizos make the ceremony more elaborate. Then the condor is liberated, and the people wait until it takes flight. Commercialized or not, it is always a very emotional moment. □

A new fossil from northeastern China's Liaoning Province offers the best evidence yet of feathered dinosaurs.

The Proof Is in the Plum

Over the past ten years, discoveries from China's Liaoning Province have been giving us rare glimpses of a fossil community near the boundary of the Jurassic and Cretaceous periods. These glimpses just keep getting better. Known as the Jehol biota, these ancient plants and animals are embedded in fine-grained sediments that preserve details: the veins of leaves and insect wings, the patterning of skin, and the filaments of feathers. Some of the fossils are proving pivotal in testing the hypothesis that birds are the living descendants of dinosaurs.

Liaoning's farmers have been collecting fossil fish and insects in the area for decades. The Chinese government now regulates fossil collection and while paleontological excavation has taken place sporadically for years, most specimens are still unearthed by local people. The Jehol fossils are enclosed in gray volcanic ash that was deposited on the bottom of shallow lakes. They are the remains of a varied community of plants and animals that perished in or near the lakes and were quickly buried. The most abundant fossils are arthropods, but plants and fishes are also common. Rarer fossils include dinosaurs, turtles, pterosaurs, lizards, and early mammals. Some specimens reveal fossilized stomach contents and skin shaded in patterns. We cannot tell what colors the patterns represent, but we do know that some Jehol animals, including insects, fish, and small dinosaurs, were spotted or striped, like their living relatives.

Among the first of the remarkable fossils of land-dwelling vertebrates to emerge at Liaoning in the 1990s were creatures called protobirds. They are more closely related to modern birds than is *Archaeopteryx* from southern Bavaria, but more primitive than birds alive today. Protobirds such as *Confuciusornis* had the same kind of feathers as modern birds; some specimens even display long tail feathers reminiscent of tropic birds and birds of paradise.

In 1996 the fossil of a small theropod—a bipedal, birdlike dinosaur—came to light and made news in the popular press as well as the scientific community. Named *Sinosauropteryx*, this creature was the first nonbird whose fossil included featherlike structures. The subsequent discovery of other small dinosaurs with feathery appendages—*Caudipteryx, Protarchaeopteryx, Beipaosaurus,* and *Sinornithosaurus*—was seen by most paleontologists as evidence supporting several hypotheses: birds are the living descendants of theropod dinosaurs; birds are not the sole feather-bearing creatures; featherlike structures preceded flight and hence did not evolve in connection with it. Some scientists accept the presence of feathers on *Confuciusornis* but reject the idea that other Jehol theropods were feathered. They suggest that these creatures are actually primitive birds, or that the featherlike impressions are from a bird that became mixed in with the skeleton during burial, or that they are internal structures related to tail or body musculature. To clinch the argument, we needed a fossil that unambiguously showed a nonavian dinosaur with a feathery body covering.

A new specimen—for now known as NGMC 91—is that kind of fossil. I examined this specimen with colleagues from the Chinese Academy of Sciences. We know that it is a dromaeosaur, a theropod and relative of *Velociraptor*. We are confident about this assignment because NGMC 91 has several features present only in dromaeosaurs, notably the second toe modified into a sickle claw and the series of elongated connections between tail segments, which serve as stiffening rods. The head, tail, and much of the body are covered with single small fibers. Other parts of the body are covered with tufts or sprays of filaments. On the back of the "arms," branched structures lie parallel to one another, just like the barbs of a modern bird feather.

Discovered by a farmer in the winter of 2000, the fossil was acquired by the National Geological Museum of China shortly thereafter. It is now on

age

Story by Mark Norell
Images by Mick Ellison

Not a bird: The juvenile dromaeosaur from Liaoning Province, China, is covered with feathery filaments from head to ankle (only the feet are bare). Like many other theropod dinosaurs, it was equipped for life as a predator. The relatively large head indicates that it was a young animal when it perished about 130 million years ago.

Entombed in fine-grained sediments of volcanic ash that preserve minute details, the skeleton of the still-nameless dromaeosaur is haloed with fibers and filaments. It measures about two feet long from head to tail tip. A small fish is visible near one foot.

Crowning glory: Featherlike structures on the top of the head (detail, left) are not the impressions of a crest or head plume, because within the fossil, several layers of the filaments are present and separated by sediments. The entire head is covered by a thick mat of the short filaments.

The head, tail, and much of the body are covered with featherlike filaments. Other parts bear long feathery tufts, or sprays.

On the "arms" and tail, the featherlike structures are bunched, originating and radiating from a single point. Except at the tip, the long tail has short filaments (far left). The longest featherlike structures are the spray of filaments on the shoulder and "arms" (the detail at left shows the shoulder, folded arm, and bent wrist.)

loan to the American Museum of Natural History and will be on display until the end of August 2001. The skeleton, including the tail, is only about twenty-four inches long and is preserved on a slab and counterslab, two halves of one sheet of rock. The size of the head—large in relation to the rest of the body—indicates that this was a young animal. The serrated teeth and sharp claws show that it was a predator, and the long hind limbs suggest that it was a fast, nimble runner.

The wings of a flying insect, below, reveal subtle shading indicative of color patterns. Bottom: Halves of a single fossil hold a cycad influorescence.

The shallow lakes that once dotted northern China were repeatedly filled in with ash from erupting volcanos.

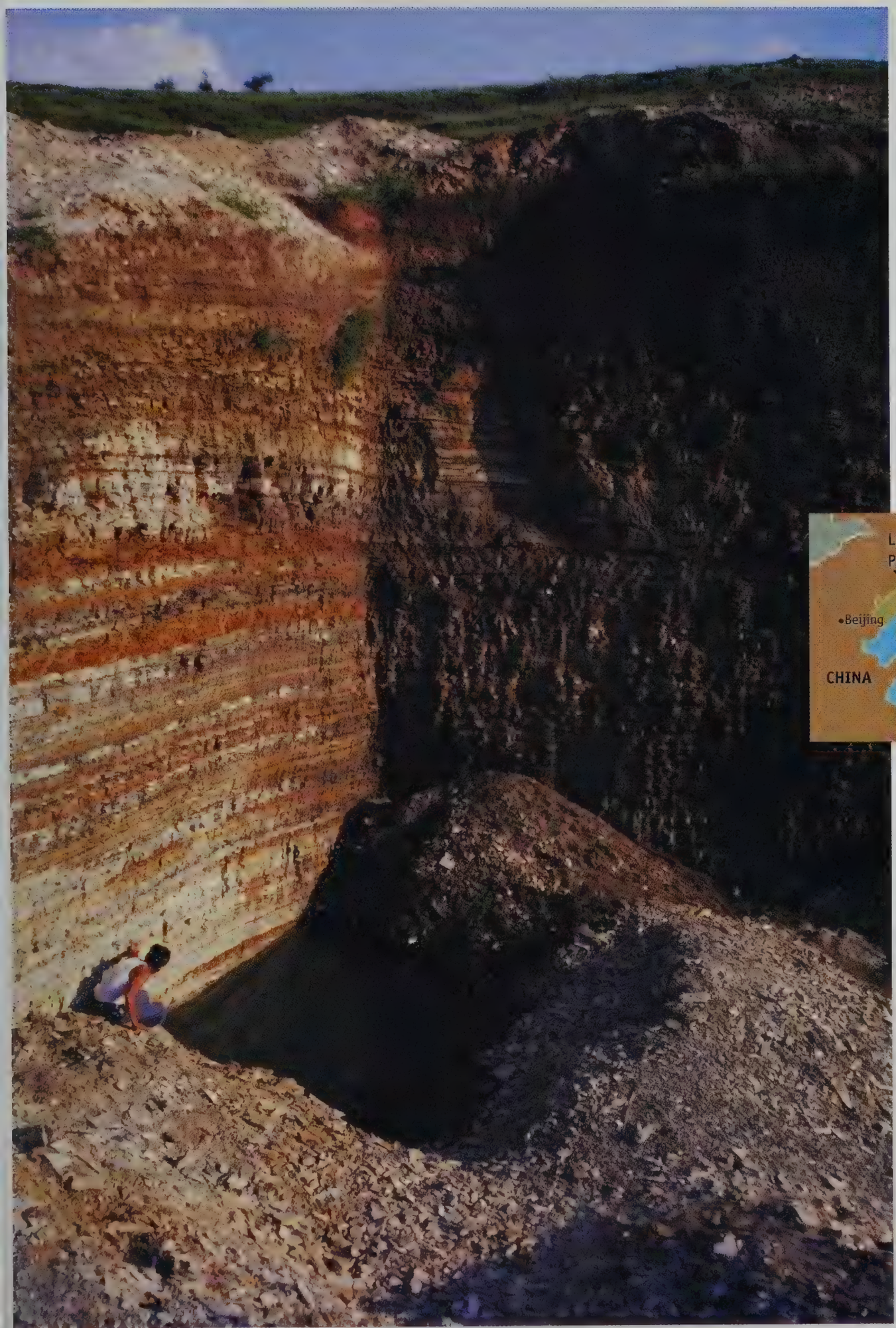
Despite the specimen's fine preservation, we are not sure to what species it belongs. A similar dromaeosaur found in the same general area and first described in 1999 was given the scientific name *Sinornithosaurus*. A few characteristics seem to indicate that NGMC 91 is a different species, yet until further research is done, we will wait to name it. (In the meantime, we call it Dave, a name from an old Cheech and Chong routine.) We know that if measurements of the bones of *Sinornithosaurus* and NGMC 91 are placed in a mathematical model that describes the growth pattern of *Archaeopteryx* (the most primitive of the protobirds), both animals deviate from the *Archaeopteryx* trajectory in the same way. So while neither grew like the protobird, they seem to have grown like each other.

Determining the age of the Jehol fossils is problematic. Groups of researchers using various techniques have come up with conflicting results. The kinds of mammals and pterosaurs found in the Jehol fossils appear to be Late Jurassic, roughly the age of *Archaeopteryx*. However, measurements of radioactive decay give dates of both 147 and 124 million years, a period that straddles the boundary between Jurassic and Cretaceous. This may not reflect error; the samples taken for analysis are from the same area but not the same quarry. The shallow lakes that once dotted northern China (and are now the fossil beds) were repeatedly and over long periods of time filled in with debris from erupting volcanos. Sets of plant and animal communities of several ages may be represented.

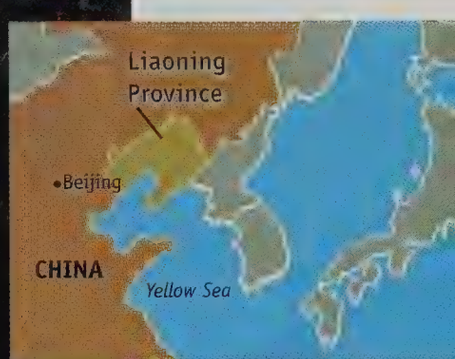
The issue of time is important. Vocal critics of the theropod theory of bird origins often point to the lack of dromaeosaurs in sediments the same age or older than those that contained *Archaeopteryx*. They argue that if dromaeosaurs are birds' closest, albeit more primitive, relatives, they should have lived at an earlier time. This argument confuses the hierarchical branching pattern of the tree of life with a direct, linear process of ancestry and descent. Taken to an extreme, this line of thought would leave one unable to explain the existence of so-called primitive mammals alive today, for example platypuses and opossums, which split off from the branch that led to placental mammals, including us, nearly 100 million years ago.

The new fossil tells us that a body covering similar to feathers was present in nonbirds. If not connected with the ability to fly, could feathers have evolved to keep animals warm? (See "First Came Feathers," September 1998.) Modern birds are warm-blooded, and feathers play an integral role in maintaining body heat. A reasonable idea, although difficult to verify, is that theropods developed featherlike structures in tandem with warm-bloodedness. Only later were the structures co-opted for flight and display.

As more evidence of ancient life comes to light, we can refine our vision of dinosaurs and birds-as-dinosaurs. If we could see the juvenile dromaeosaur that hunted along the lakes of Liaoning, the best way we could describe it would be: Like a bird. Strange, but like a bird. □



Beneath the green farm country of Liaoning, northeast of Beijing, layers of sediment preserve communities of organisms that lived in and near ancient lakes: plants, insects, small dinosaurs, birds, fish, various reptiles, and mammals.



BIOMECHANICS

Got Silk?

Whether catching a fly or a bullet, few materials can match the toughness of silk.

Story by Adam Summers ~ Illustration by Sally J. Bensusen

In 1887 an obscure California medical journal published a frontier physician's observations on the remarkable properties of silk. The doctor, George Goodfellow, noted that silk scarves and handkerchiefs were impenetrable to the bullets with which the ne'er-do-wells of Tombstone, Arizona, were shooting one another. Since then, a good many engineers, biologists, biochemists, and physicists have spent time trying to unravel the mystery of silk's resilience. Much of the early research focused on the silk spun by silkworms for their cocoons (and used in the making of parachutes and pantaloons, as well as scarves and hankies) because these caterpillars can be easily farmed. Spider silk, however, turned out to be an even better material for warding off projectiles. Recent research has revealed the molecular as well as the genetic basis for the way different types of spider silk behave under stress.

Examine an orb weaver's web early in the morning, when it is still

covered with dew. Radiating from the center are strands of frame silk, which form a grid that supports the network of capture-silk threads. Right away, you'll notice that the capture threads sag under the weight of the dewdrops, while the strands framing the web shrug off the added burden. The frame, or dragline, silk is stiff and strong but not at all sticky. By contrast, the fly-catching capture threads in the spiral of the web are made of viscid silk—a strong, stretchy thread covered with droplets of glue. Spiders produce other types of silk (to wrap prey, for example), but these two types have been the main focus of biomechanical research.

John Gosline and colleagues at the University of British Columbia have been investigating the differences between dragline and capture silk. In particular, they are interested in three properties: stiffness, strength, and toughness. Stiffness refers to how much the silk resists when pulled, while strength is a measure of how much force it takes to break a strand of a given diameter. Dragline silk is about as stiff as nylon thread and, pound for pound, stronger than steel cable. Capture thread, which stretches like rubber, is not stiff at all, but it still has nearly one-third the strength of steel. Though these qualities are impressive, some man-made materials can match silks in both stiffness and strength. The toughness of spider silk—its ability to withstand a sudden impact without breaking—is quite another matter, however, and one of special interest to the military and to industry.

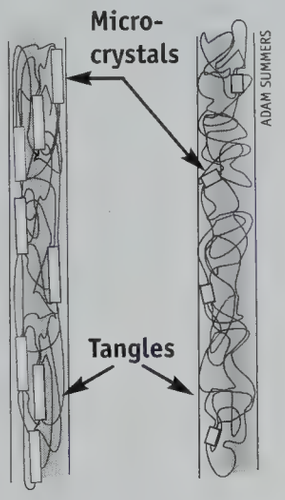
Some materials fracture when struck or yanked on; others give ground but don't break unless more energy is used. Kevlar, the fiber found in bulletproof vests and bicycle helmets, has less energy-absorbing capability than does either dragline or capture silk. Dragline silk is especially remarkable in this regard: when weights are dropped on this type of silk, it can absorb up to ten times more energy than Kevlar can. On impact, most of the kinetic energy dissipates as heat. From the point of view of a hungry spider, this is much better than storing it as elastic energy—which might simply catapult a prey item right back out of the web.

Industrial interest in producing artificial spider silk has led to the cloning of certain spider genes that specify the proteins, called fibroins, that make up the silk. Some of these cloned genes have been inserted into goats, whose milk now contains "harvestable" fibroins. Ultimately, many researchers hope to create synthetic, enhanced genes and to produce commercially viable quantities of fibroins to be spun into miracle fibers for everything from brake pads to surgical sutures.

Genetic research has shown that the dragline fibroin molecule has two, quite different components: highly organized microcrystals (20–25 percent of each molecule) and amorphous, spaghetti-like tangles. The microcrystals form linkages between fibroin molecules. The amorphous tangles are dry, rigid, and glassy, giving the fiber its stiffness. Unlike glass, however, this material is not brittle. As the silk is pushed and pulled, the tangles straighten out, allowing the material to stretch without breaking. Dragline silk can be stretched by about 5 percent and still bounce back. Stretching it more than this permanently changes the configuration of the fibroins (primarily in the amorphous tangles), and the silk is unable to regain its shape. However, the thread doesn't actually rupture until it has been stretched by 30 percent of its resting length; Kevlar fibers snap when extended just 3 percent.

A molecule of capture fibroin is made of the same two components but in very different proportions: it consists almost entirely of tangles, with very few microcrystals. In addition, hydrated glue on the surface of capture silk keeps the strands moist, thus rendering them even less brittle than dragline silk. Rubbery and viscid, this silk stretches up to about three times its length when pulled on and takes a good deal of abuse before breaking—an important quality in a material responsible for entangling prey.

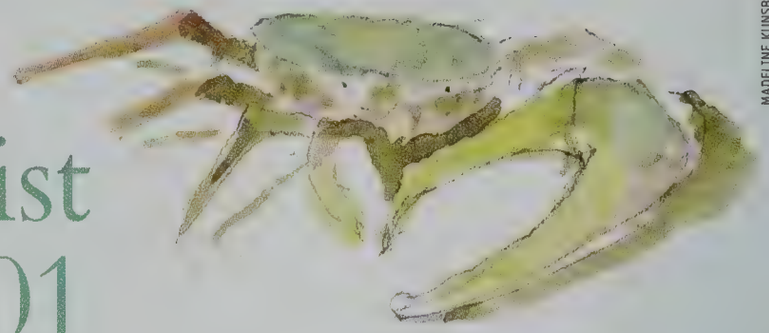
A simple change in the relative amounts of the two fibroin components, and the addition of a gluey coating, thus results in very different behavior. If fibroin can be engineered with just the right proportion of crystalline regions, manufacturers might be able to produce garments that are stretchy enough to be comfortable and fashionable, yet stiff enough to protect the underlying skin. Bulletproof T-shirts anyone?



The protein molecules of dry dragline silk are made up of spaghetti-like tangles and many tiny crystals (all oriented the same way). In sticky, stretchy capture silk, the molecules consist almost entirely of tangles, with very few crystals (pointing every which way).

Adam Summers is an assistant professor at the University of California at Irvine.

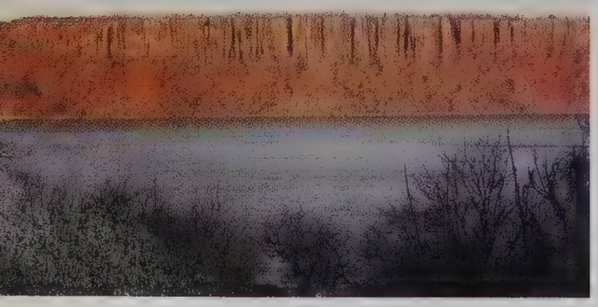
AT THE MUSEUM


MADELINE KUNSBERG

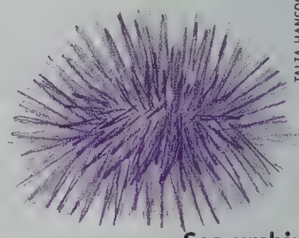
Young Naturalist Awards 2001

For the American Museum of Natural History's fourth annual Young Naturalist Awards, students in grades 7 through 12 were invited to embark on an expedition that focused on a topic in biology, earth science, or astronomy and to document their observations and analyses of the natural world. The winning entries (selected from nearly a thousand) are summarized below. Full-length versions are available in a catalog published by the Museum's National Center for Science Literacy, Education, and Technology and online at www.amnh.org/nationalcenter/youngnaturalistawards/.

Shaped by Nature and Man: The Geological History of the Palisades, *by Max Arno (Hastings High School, Hastings-on-Hudson, NY; Grade 10)*
Along the lower Hudson River rises a series of sheer cliffs known as the Palisades—400 feet high and 200 million years old. Max Arno describes their majesty this way: "My eyes trace the ancient sill of lava curving around the land like a gigantic fortress. Glancing down, I can see the jagged wall of rock plunging straight down. I am fascinated by the thought that continental plates once collided and then pulled apart, and huge glaciers swept across the very spot on which I stand." Not only does Max delineate the cracking, compression, grinding, and polishing that formed these "stark vertical cliffs," but he also explores the Palisades' commercial history—how the rocks were quarried to build Manhattan's brownstones and to pave its streets (in the late 1800s, one firm alone took out 12,000 cubic yards of traprock a day).


MAX ARNO
The Palisades

Tide Pools and the Life Within Them, *by Talia Hancock (Aliso Viejo Middle School, Aliso Viejo, CA; Grade 7)*
Talia Hancock, who has always lived near the Pacific Ocean, and who visits the seashore most days, is intrigued by the array of creatures living in tide pools. She dedicated four autumn study sessions to pools at Doheny State Beach in southern California, taking care to visit at different times of the day and to focus on different animals. She writes, for example, that chitons are "about half an inch long and use raspy files on their feet to scrape off algae from the rocks to eat. They have eight sections that let them cling to uneven rocks. Chitons usually eat at night, so I wasn't able to observe them eating." Talia plans to further her research by "learning about how to protect tide pools and the endangered animals in them."


TALIA HANCOCK
Sea urchin

Birding Sector 7, *by Daniel Hinnebusch (Upper St. Clair High School, Pittsburgh, PA; Grade 11)*
"Normal teenagers do not wake up at two in the morning and drive south for half an hour to look for owls," confesses Daniel Hinnebusch, describing an owling expedition. "Normal teenagers have not even heard of the Christmas Bird Count, an international citizen science bird count that takes place within two weeks of the 25th of December." This bird count (his fourth) and owling expedition (his second) took Daniel to seven sites in the Pittsburgh area within fourteen hours. He logged seventy-six miles by car, eleven miles on foot, and thirty-eight species.

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Daniel concludes that the Christmas Bird Count is important because it "collects a massive amount of data on the abundance of bird species throughout the United States and other parts of the world."

Tardigrades As Environmental Bio-Indicators, *by Amber Hohl (Central Lee High School, Donnellson, IA; Grade 12)*
In sixth grade, Amber Hohl fell in love with tardigrades, microscopic invertebrates that inhabit mosses and lichens. Since their hosts "sponge up everything the air brings their way—carbon dioxide, sulfur dioxide, heavy metals, radiation, and dust," Amber wondered if tardigrades did, too. She soon demonstrated that living downwind of the coal-fired James River Power Plant in Springfield, Missouri, adversely affected their population. To her amazement, her interest in tardigrades led to recent summer fieldwork in Greenland, with fifteen tardigradologists from around the world. There, from a radioactive spring, or "hot zone," Amber collected several moss samples; in one, she observed a rare occurrence: tardigrade carnivory. She looks forward to the prospect of making a "contribution to the discovery of scientific truth."

Nesting Habits of the Barn Swallow *(Hirundo rustica)*, *by Elspeth Iralu (Home School Program, Gallup, NM; Grade 8)*
Barn swallows nearly always keep the same mate all their lives and migrate every year back to their nesting places in North America from as far south as Argentina. The more Elspeth Iralu watched two pairs nesting on opposite corners of her front porch in New Mexico last year, the more engrossed she became, especially in examining their nests and learning how she could facilitate the birds' nest building and repair. This past summer, each swallow couple raised three sets of young. Elspeth had the opportunity to observe all kinds of behavior; perhaps the quirkiest occurred when she played *The Best of World Music* on her family's CD player "just to see the barn swallows 'dance.' "

REBECCA KANE

Pitcher plant

Bog Trotting, *by Rebecca Kane (Home School Program, Lee, NH; Grade 8)*
Lee Hill Bog in New Hampshire has a history that goes back about 10,000 years—when glaciers from the Ice Age retreated, leaving a poorly drained pond in which dying vegetation decomposed and turned to peat. Rebecca Kane analyzed three stages of bog formation as represented by Lee Hill Bog and two nearby ponds, observing that "bogs are so acidic that for plants it is as if they are trying to live in a pond full of orange juice." After visiting the bog one day last September, she recorded her amazement at its variety of life: "The leaves have all turned and the cotton grass has gone to seed. I can hear the songs of migrating birds: phoebes, white-throated sparrows, towhees, catbirds, chipping sparrows. I push through the underbrush, looking for pitcher plants. I find some. Each clump is a different color: some are a deep, shiny red; some are a bright green; and others are bright green but with a network of veins that look as if they are carrying blood. I split one open and find at the bottom all the plant's recent victims."

A Day at the (Barrier) Beach: My Expedition to Sandy Hook, *by Madeline Kunsberg (Home School Program, Maplewood, NJ; Grade 9)*
"A barrier island has a natural defense against erosion: it moves," writes Madeline Kunsberg, describing the "littoral drift" that continually changes the formation of New Jersey's Sandy Hook. This long, narrow area of dunes and forestland looks "like a curved, brown finger protruding from the northeast coast of New Jersey." Madeline discovered that "over the last 250 years, Sandy Hook has been two

MADELINE KUNSBERG

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and three separate islands, and now it is technically a 'barrier spit,' not an island, with a sandy bridge created by the refraction of incoming waves." The vegetation varies, from beach grass and Virginia creeper stabilizing the dunes to eastern red cedar and even prickly pear. Joining an organized science outing, she collected both ocean and bay water samples to test their pH, ammonia, nitrite, and dissolved oxygen content. Madeline spent part of her day, however, scrambling out of poison ivy and the cold undertow. "Perhaps the most memorable lesson of the day was that expeditions never go as planned," she comments.

How Do Humans and Plants Interact in Tidal Wetlands? *by Bianca Male (Thomas Jefferson High School for Science & Technology, Alexandria, VA; Grade 9)*

"Stepping off of our noisy bus into the frigid morning air, I am immediately astounded by the primal beauty of the marsh," writes Bianca Male at the beginning of her field journal devoted to a tidal wetland area at the Prime Hook Wildlife Refuge in Delaware. "The golden and magenta sunrise highlights the background, silhouetting the graceful cordgrass as it dances in the biting wind, and reflecting shards of sparkling light on the glassy water." Although the area appears pristine, Bianca soon sees that invasive *Phragmites australis* is beginning to choke areas of native *Spartina alterniflora* (salt marsh cordgrass), which "plays a major role in the detritus-based food web that supports the marsh ecosystem." Plastic wrappers, cigarettes, soda cans, and a discarded shoe further mar the "glittering, wind-whipped water." Bianca ends her journal "pondering not what the marsh will look like in coming years, but whether it will even exist at all."

An Essential Mineral, *by Frieda Shmuel (Woodland Middle School, East Meadow, NY; Grade 7)*

At 1,300 feet below sea level, Israel's Dead Sea is the lowest point on earth. "Stepping into the Dead Sea was like stepping into a hot cup of tea," observes Frieda Shmuel, who visited it with her family. But what really fascinated her was the sea's exceptionally high salinity. After returning home, Frieda decided to investigate the properties of salt and to conduct an experiment comparing salt crystals from the Atlantic Ocean with those from the Dead Sea. She writes,

MAX SHMUEL

Comparing various salt crystals

"I have never thought of salt as valuable. It just has always been there." But without salt, she continues, "we wouldn't be able to survive. Human blood has salt, tears have salt, and body cells cannot function without salt."

First Flights: Fledgling Bald Eagles in Southeast Alaska, *by Caitlin Stern (Home School Program, Haines, AL; Grade 12)*

Alaska's Chilkat Valley is "the site of the largest bald eagle congregation in the world," which happens each fall, while the salmon are running. For the past three years, Caitlin Stern has participated in a bald eagle ecology study there. Last summer, Caitlin observed bald eaglets fledging from nests at two sites. Spending lengthy hours patiently watching the eagles (and avoiding the many brown bears at one site) allowed her not only to forget herself but also "to discover the wonders of the wide array of other organisms that are part of the environment here. The environment of any one place is vastly complex. By studying one organism, you can begin to see the many ways it is related to and dependent on its environment. Through these eagles, I have come to better understand the place in which I live."

Investigating Vegetation and Small Mammals, *by Jennifer Vrentas (State College Area High School, State College, PA; Grade 11)*

On a three-week expedition to the Cloud Peak Wilderness Area of Wyoming's Bighorn Mountains, Jennifer Vrentas focused on the biology of three habitats around one stream, Oliver Creek. She examined changes in vegetation at increasing distances from the creek, the types and diversity of small mammals, differences in soil samples and air conditions, and

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JENNIFER VRENTAS

Identifying macroinvertebrates in Oliver Creek

various types of macroinvertebrates. Joining her high school group were seventeen students from a high school in Edinburgh, Scotland. Not only did Jennifer get to camp for the first time in her life, but she also "marveled over how the Scots supposedly spoke the same language as we did yet used so many foreign words. Their use of 'trainers' for sneakers, 'minging' for disgusting, and 'Philadelphia' for any type of cream cheese prompted us to put together a Scottish-American dictionary."

Exploring a Woodlot's Ecosystem, *by Susan Wiedmeyer (Mukwonago High School, Mukwonago, WI; Grade 10)*
"I never originally thought of my backyard as an 'ecosystem,' but this expedition has helped me see how all living and nonliving things are connected through intricate relationships," writes Susan Wiedmeyer, who has enjoyed exploring this "wooded sanctuary" since she was a toddler. House wrens and chickadees compete for

SUSAN WIEDMEYER

Woodlot creatures

cankerworms and caterpillars; wood ducks, gray squirrels, flickers, and screech owls fight for the same nesting sites. She notices the intricate food webs that connect everything in the woodlot to the nitrogen cycle, and, echoing her relatives' comment "My, how you have grown" (delivered at family reunions), she says, "In the same way that I am always changing, so is the ecosystem in my backyard." □

MUSEUM EVENTS

DURING JULY AND AUGUST

Photographs of primates collected during the American Museum Congo Expedition (1909–1915) are now on display in the Museum's library. (You can also view them at library.amnh.org/staging/diglib/primates.html.) This coming fall, the Museum's Digital Library Program will offer comprehensive on-line access to the expedition's photographs, field notes, scientific publications, and artifact and specimen data—all compiled by Museum scientists Herbert Lang and James Chapin during their six years in Africa. Generous support for this project has come from the Andrew W. Mellon Foundation.

Chimpanzee

HERBERT LANG/AMNH

IMAX Theater: *Lost Worlds: Life in the Balance* (biodiversity and the need for conservation); *Shackleton's Antarctic Adventure* (the dramatic story of the 1914–17 British Imperial Trans-Antarctic Expedition); Opening July 14—*Bears* (natural history of the grizzly, polar bear, and various other species).

The American Museum of Natural History is located at Central Park West and 79th Street in New York City. For listings of events, exhibitions, and hours, call (212) 769-5100 or visit the Museum's Web site at www.amnh.org. Space Show tickets, retail products, and Museum memberships are also available online.

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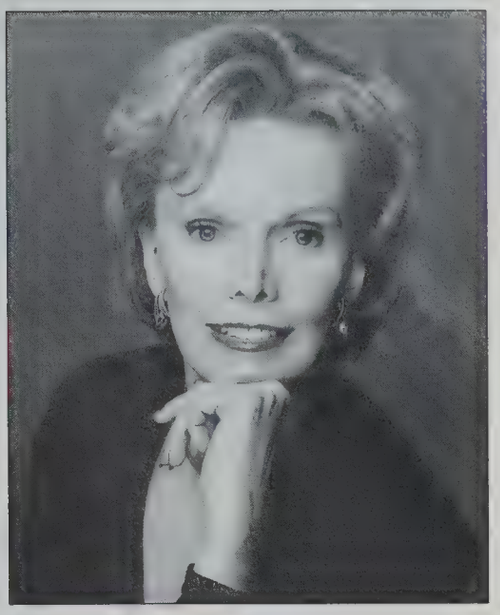

by Leil Lowndes

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REVIEW

COMPOSITE IMAGE: WERNER LAYER; ANIMALS ANIMALS/SHIN YOSHINO; MINDEN PICTURES

A Down-Under Look at North America

What if we returned not just mustangs and burros but also elephants and lions to our continent's wilds?

By David A. Burney

In the movie *Crocodile Dundee,* Paul Hogan's tough but endearing Outback character eventually winds up in New York City and treats Americans to a refreshingly topsy-turvy view of themselves. The same approach works fabulously in Aussie mammalogist Tim Flannery's bold new book on the ecological history of North America, *The Eternal Frontier.*

Flannery opens the book with a bang—the bang at the end of the Cretaceous, 65 million years ago, when North American conifers and dinosaurs were erased in the wake of an asteroid impact in Mexico. The result was the complete reordering of the continent's life forms—mixing diminutive survivors with new arrivals. Land bridges formed and dissolved, letting in immigrants from eastern Asia, Europe (via Greenland), and South America.

The evolution of North American flora and fauna has been affected by the continent's pronounced sensitivity to climate change. This landmass, writes Flannery, is "a great thermal trumpet," an "inverted wedge with a 6,500-kilometer-wide base deep in the sub-Arctic [that] narrows until it is reduced to a peninsula just sixty kilometers wide" in the Central American isthmus. Unlike Eurasia, a continent at similar latitudes but with mountain ranges that run predominantly east to west, our great Rocky and Appalachian mountain chains run north to south, funneling superchilled arctic air south in winter and warm air from the Gulf of Mexico north in summer. The continent has thus been hit hard by the drastic climate shifts that have contributed to biotic turnovers every 10 million years or so since the dinosaurs bowed out. Flannery's chronicle of evolutionary triumphs and setbacks, foreign invasions, and the rise of some continental specialities—such as horses, camels, dogs, and even cheetahs—would alone make the book worth reading. But the author really warms to his subject as he begins to discuss ice ages.

The Eternal Frontier: An Ecological History of North America and Its Peoples, *by Tim Flannery (Atlantic Monthly Press, 2001; $27.50)*

For instance, how many North Americans, before reading this book, would have reflected that during the glacial phases of the Pleistocene Epoch (from 1.6 million to 10,000 years ago), the earth's largest ice mass was located not on Antarctica but on the northern half of our own continent? How many would have considered the array of now vanished megafauna, including elephants and lions, that roamed North America before the troublemaker *Homo sapiens* arrived here just at the end of the Ice Age?

Flannery speaks with all the bravado of Dundee himself on various human-related controversies that have preoccupied many of his North American colleagues. On the "pre-Clovis" debate, Flannery argues against humans having arrived in North America before 13,000 years ago, drawing parallels to the archaeological records of Australia's Aborigines. He likewise casts doubt on prevailing climatic explanations for the extinction of such animals as mammoths and sabertooths at the end of the Pleistocene, arguing that climatic changes at the end of ice ages elsewhere did not result in megafaunal collapse.

Another theory receiving attention these days—promoted by American Museum of Natural History mammalogist Ross MacPhee and others—is

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that an as-yet-unidentified disease introduced by humans killed three-quarters of the North American large-bodied genera. This idea rates a single sentence from Flannery. He does, however, hold with a theory first championed in the 1960s by Paul S. Martin, who argued that the earliest Americans were extraordinarily effective big-game hunters. Because the animals had never known threats from humans and had no innate or learned escape routines for eluding spear-wielding carnivores, they were extinguished across the Americas about 13,000 years ago by the so-called Clovis people.

Continuing his bold romp through the maze of North American paleotheories, Flannery contends that Clovis culture collapsed with the disappearance of the big animals, that Native American cultures found ways to adapt to the altered environment, and that Eurasian immigrants such as bison and elk replaced the extirpated mammoths, horses, and short-faced bears. Some of these species may have come across the land bridge at about the same time as the first humans and thus were preadapted to human predation. Others—contemporary wilderness symbols such as the wolf, moose, and grizzly bear—probably reached the Lower 48 somewhat later than humans.

With uniquely Australian panache, Flannery describes Europe at the time of its discovery of the New World as a "backwater." He draws on the ideas of historian Frederick Jackson Turner to explain the emerging and distinctive North American form of the frontier mentality. As in his other books (such as *The Future Eaters: An Ecological History of the Australasian Lands and People*), Flannery shows genuine empathy for the plight of the aboriginal peoples who lost their land to the greed of white settlers and their lives to the settlers' diseases and guns.

As the United States became the world's greatest technological and economic force, the pioneer spirit found itself for the first time without a frontier. "By the 1950s North Americans had eliminated about four-fifths of the continent's wildlife, cut more than half its timber, all but destroyed its native cultures, dammed most of its rivers," and done other damage as well, he writes, adding that they had "created one of the most affluent and self-contented societies ever seen, yet still the pillage of their natural resources was not finished."

Some who study the past propose, as does Flannery, nothing less than reestablishing evolutionary trends that were snuffed out by humans on this continent within recent millennia. Going well beyond the usual pleas for conservation and ecological restoration, Flannery looks deeply into his crystal ball: "I believe that the great question faced by park managers in North America today is whether, where suitable, they should introduce elephant, camel, Chacoan peccary, llama, panther, and lion into their reserves." In 1999, while Flannery's book was being written, Paul Martin and I published an article in *Wild Earth* entitled "Bring Back the Elephants!" We suggested that Americans should at least consider the evolutionary and ecological arguments in favor of careful experimentation along these same lines, so Flannery is a welcome ally. "Given the fact that the continent has never supported a more impoverished mammal fauna in the last 50 million years than it does at present and that the existing fauna is unbalanced," he suggests, "appropriate introductions are more likely to be beneficial rather than deleterious."

Watch out, fellow North Americans. This gutsy Aussie may have read our landscape and ecological history with greater clarity than any native son.

David A. Burney, of Fordham University, has conducted field studies on extinctions and environmental change in Africa, Madagascar, Hawaii, the West Indies, and his native North America.

nature.net

Bad Astronomy

By Robert Anderson

It's a sobering experience to examine common myths that are perpetuated as scientific fact by supposedly educated people. With so much bad science floating about, how is the average person to know what's true and what's not? A few crusaders have taken it upon themselves to set the rest of us straight. Sonoma State University astronomer Philip Plait is one of them, and everyone is fair game in the humorous (and educational) critiques at his web site, www.badastronomy.com.

According to Plait, it's the everyday misconceptions that are "the heart and soul of Bad Astronomy." One of his favorites to debunk is that you can stand raw eggs on end only on the vernal equinox, since in reality this feat is possible any day of the year. Apparently, this myth originated with a U.S. reporter in China who happened to observe the custom of egg balancing on *Li Chun*—which for the Chinese is the first day of spring, celebrated in early February (some six weeks before the vernal equinox). Her article appeared in the March 19, 1945, issue of *Life;* United Press picked up the story; and we have been saddled with the egg myth ever since.

A stickler for truth and accuracy, Plait also takes on the bad astronomy spread by the movies and television—particularly NBC's error-ridden made-for-TV movie *Asteroid* and Fox Television's "Conspiracy Theory: Did We Land on the Moon?"

"I may be bucking the odds," Plait writes, "but I can dream that someday this virus will be stamped out, and Good Astronomy will prevail."

Robert Anderson is a freelance science writer living in Los Angeles.

Encyclopedia of Astronomy and Astrophysics, *edited by Paul Murdin (Nature Publishing Group/Institute of Physics Publishing, 4 vols., 2001; $650)*

A single entry in this encyclopedia concentrates more physics into a few paragraphs than the average layperson encounters in a lifetime, yet the style is clear and direct, and the curious reader will be able to grasp many of the concepts even without a hard-core physics background. This comprehensive, nearly 4,000-page work contains more than 2,700 entries, including 650 in-depth subject articles (each with references and bibliography), 780 definitions of astronomical terms and objects, 650 biographies, and various lists and catalogs, as well as 3,500 illustrations and much more. The searchable online version, www.ency-astro.com, includes extensive links and quarterly updates.

Handbook of the Birds of the World, vol. 6: Mousebirds to Hornbills, *edited by Josep del Hoyo, Andrew Elliott, and Jordi Sargatal (Lynx Edicions/BirdLife International, 2001; $185)*

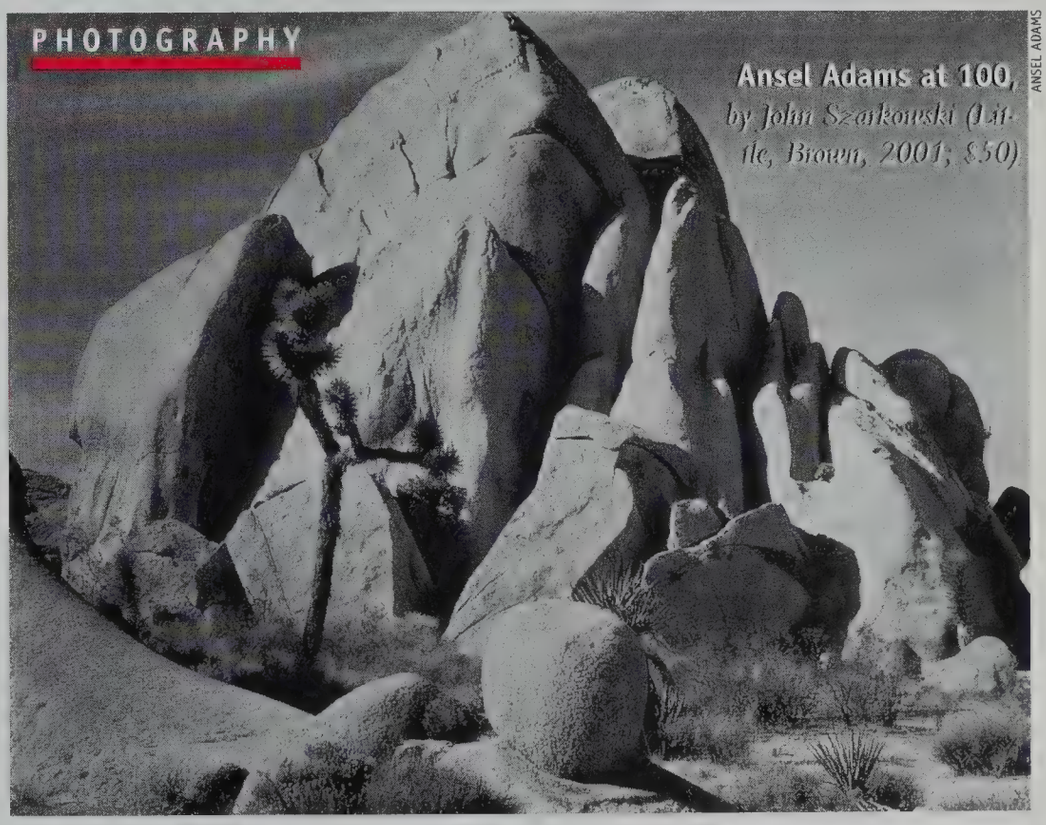
This gorgeous sixth volume in a projected twelve-volume, folio-sized series (intended to be the definitive handbook of the world's 9,000-plus living species of birds) became, according to the editors, so massive that they decided to limit its scope to three orders of classification, encompassing twelve families: mousebirds, trogons, kingfishers, todies, motmots, bee-eaters, rollers, ground-rollers, cuckoo-roller, hoopoe, woodhoopoes, and hornbills. Each family is discussed in terms of morphology, habitat, voice, breeding, and many other aspects, and each species merits an extremely detailed entry. The photographs and paintings are spectacular. A multifaceted foreword on avian vocalization, drafted by the late Luis F. Baptista and completed by Donald E. Kroodsma, runs more than thirty pages. Already published in this splendid series are *Ostrich to Ducks* (vol. 1), *New World Vultures to Guineafowl* (vol. 2), *Hoatzin to Auks* (vol. 3), *Sandgrouse to Cuckoos* (vol. 4), and *Barn Owls to Hummingbirds* (vol. 5).

Encyclopedia of Biodiversity, *edited by Simon Asher Levin (Academic Press, 5 vols., 2001; $695)*

The "story of a complex, self-organizing system—the biosphere—whose pieces can be examined individually, but cannot be understood outside the context of the whole" is told in 313 lengthy articles, each with a glossary, a bibliography, and cross references. "Fungi," for instance, has seven sections covering aspects from how fungi grow and the environmental niches they occupy to their industrial uses and the implications for species endangerment. The encyclopedia has a second story to tell, writes the project's editor in chief: "The coevolution of the biosphere and *Homo sapiens,* the first species whose own activities can feed back to influence the evolution of the biosphere on time scales that could lead to its own demise." For the online version, go to www.apnet.com/idealreferenceworks/.

The Oxford Companion to the Earth, *edited by Paul L. Hancock and Brian J. Skinner (Oxford University Press, 2000; $60)*

Concise discussions of our planet's myriad habitats—from deserts and wetlands to mountains, caves, glaciers, and coral reefs—make up only a fraction of the more than 900 entries written by 250 contributors. Entries range from natural phenomena (tornadoes, tsunamis, volcanoes, earthquakes, jet streams, weather fronts) and key figures in earth sciences (Agassiz, Cuvier, Darwin, Lamarck) to ecological concerns (acid rain, the ozone layer, waste disposal, the enhanced greenhouse effect) and land formations (sinkholes, fiords, yardangs, deltas). This volume, although weighty, could conceivably be a field companion.



The books mentioned are usually available in the Museum Shop, (212) 769-5150, or via the Museum's Web site, www.amnh.org.

THE NATURAL MOMENT

Spray It Again!

Photograph by **Theo Allofs**

Pelicans are well known for the elastic pouches in their lower jaws that sometimes serve as scoops for capturing fish and at other times become three-gallon buckets from which their young feed on regurgitated chowder. Despite this massive foldaway equipment, pelicans are graceful fliers that soar together in flock formations.

The world's eight species of pelicans are found near lakes, seashores, and lagoons in the Americas, Africa, Asia, Europe, and Australia. The Australian pelican, *Pelecanus conspicillatus,* is found all along the coast of the island continent. Like most other kinds of pelicans (but unlike American brown pelicans), this Australian species participates in cooperative hunts for fish. Many birds, beaks open, swim in lines toward the shore, some beating their large wings against the water's surface to drive their prey into the shallows.

Although pelicans normally obtain freshwater from the fish they eat, this individual, which lives near Shark Bay Marine Park in the state of Western Australia, makes daily visits to a local resident's garden to drink from a lawn sprinkler. According to park rangers, it is a descendant of a female that lived beside the Indian Ocean some years ago. Having injured her wing, she was captured and cared for by the rangers and, while incapacitated, learned to gulp freshwater at a sprinkler. After healing, she was released, but eventually returned with her offspring to the same sprinkler, where they also picked up the habit of taking a refreshing afternoon drink. The pelican shown here may be a member of the third generation of sprinkler drinkers.—*Richard Milner*

ENDPAPER

Slow & Barefoot

How to walk on the wild side

By Robb White

My mother was the slowest kind of person. When my two sisters got divorced (both at about the same time), they got into the habit of walking for miles around our old home place in Georgia for exercise. Momma went too, for company and commiseration, but it didn't work out. Every afternoon, those fast-walking women would do two or three laps to Momma's one. My sisters told me that one time, when they passed her after

KEVIN FLEMING/CORBIS

their first lap, Momma was bending over in the middle of the little dirt road with her head down, and they were worried she'd had some kind of heatstroke, but she was just watching the doings in an ant bed. Miles later, when they passed her the second time, she was still in the same place doing the same thing. She showed them the winged bodies of all the male ants of the colony scattered around the little mound where their wingless sisters had dragged them. "They killed them, and now they're hauling off the bodies," said Momma. "Good idea," growled my oldest sister.

When I was a little boy, I was like my mother in one way. I was so fascinated by ants, wasps, and doodlebugs that I would have squatted in the road all day too, but unfortunately I did not inherit the slow gene. I was so twitchy that when I found something interesting, I would stomp all the grass around it to death during my observations. When Momma went walking, she would always come back with stories about how she had watched a whole nest of newly hatched baby lizards dig themselves out of the ground, or seen a snake swallow another snake, or caught the mating of a pair of pileated woodpeckers. I would squirm with envy and head straight out to see what I could find too, but all I came home with were scratches on my legs and tater-rows of dirt on my neck. My mother was not one to volunteer advice, even to her children, but I finally slowed down enough to ask her why she saw so much and I saw so little. "You walk too fast," was all she had to say about it.

She was right. I guess if those days had been these days, the school would have diagnosed some kind of ailment and doped me down with some pills. My mother dealt with my wigglesomeness in another way. She wouldn't let me in the house except when I was so hungry I had to sit still to eat or so sleepy I couldn't wiggle another wag. I'm still like that. When my good young doctor (also an animal watcher) tried to regulate my calorie intake to modify my blood chemistry a bit, I lost so much weight the first week that he was astonished. "You must have a metabolic rate about like an insectivore," he said. What I'm saying is that my own nature made it very hard for me to get close to nature when I was a little boy. That is, until I started going barefoot.

There is another errant gene in the family—this one causes serious inflammation of the Achilles tendon in some of us when we wear shoes. It first happens when we are about half grown, and the only thing to do is to leave those shoes off for the rest of our lives.

Having to go shoeless was the best thing that ever happened to me. It is impossible to walk too fast through brier woods when you don't have any shoes on. I started seeing box turtles copulating; baby birds hatching out; gopher tortoises laying eggs; grasshoppers, millipedes, and all kinds of other arthropods mating; baby quail and turkeys hiding; and hawks standing on the ground and eating doves, squirrels, and cotton rats. Deer were everywhere.

So what happened to the slow gene? I have a very slow four-year-old grandson, and just the other day I saw him squatting in the yard looking at something.

"What you see there, Will?"

"Look at what these ants are doing, Pop-Pop. The little ones that don't have any wings are killing the big ones that do have wings and dragging them off."

Robb White builds wooden boats in Thomasville, Georgia.

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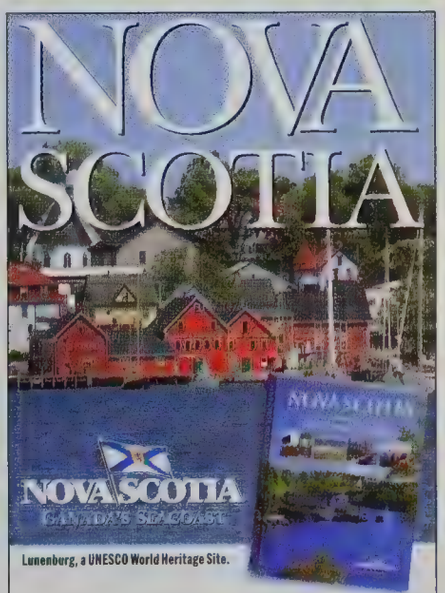

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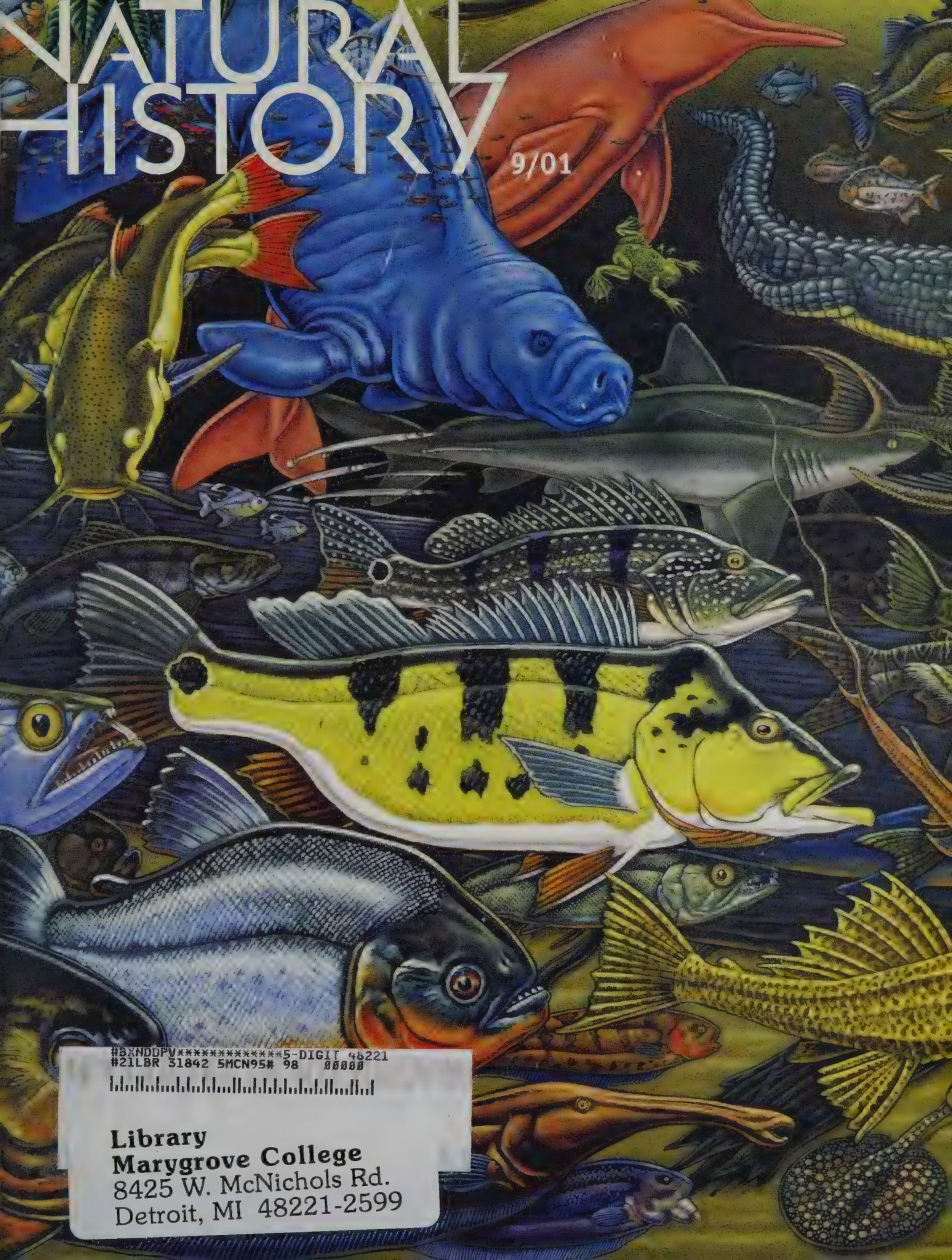

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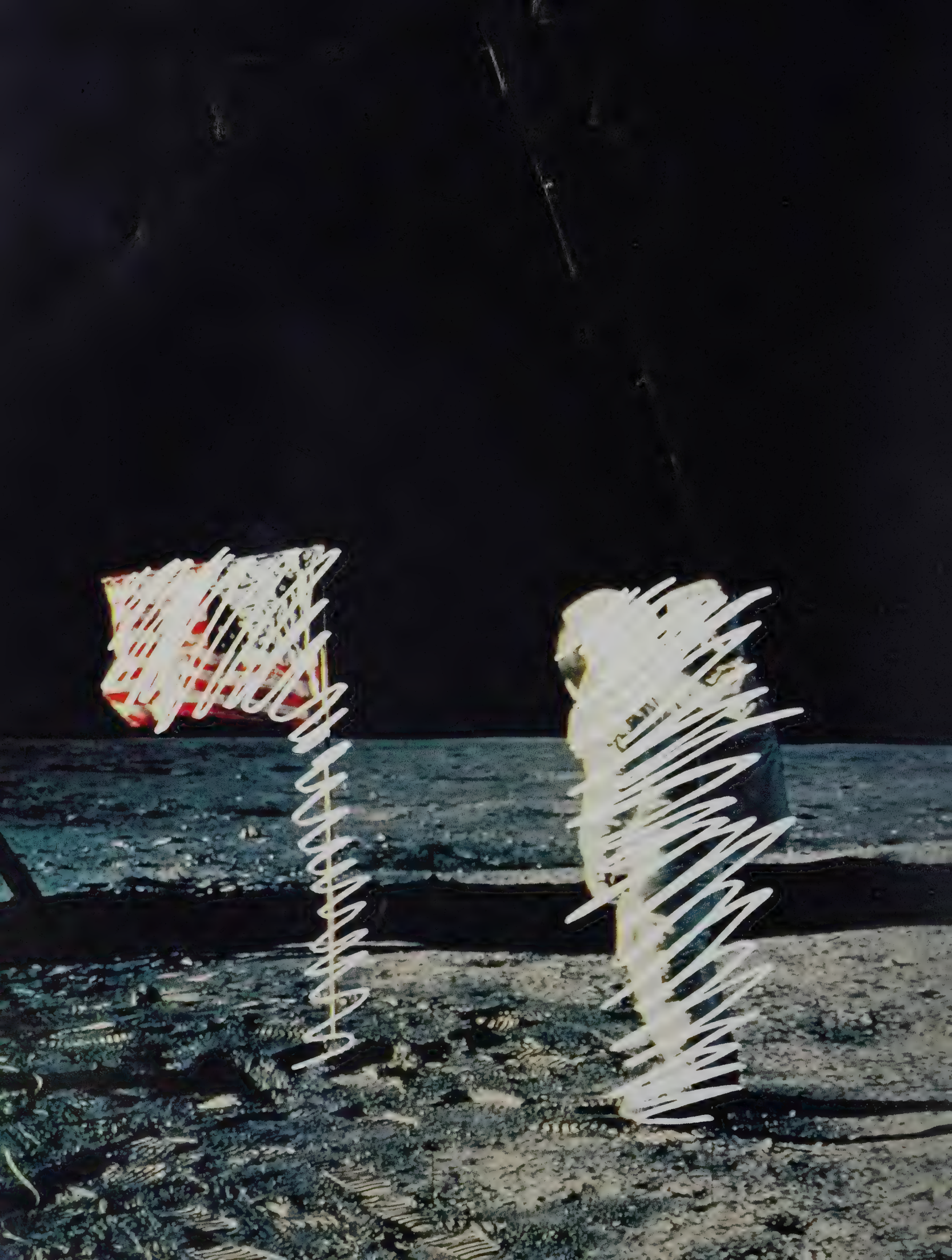

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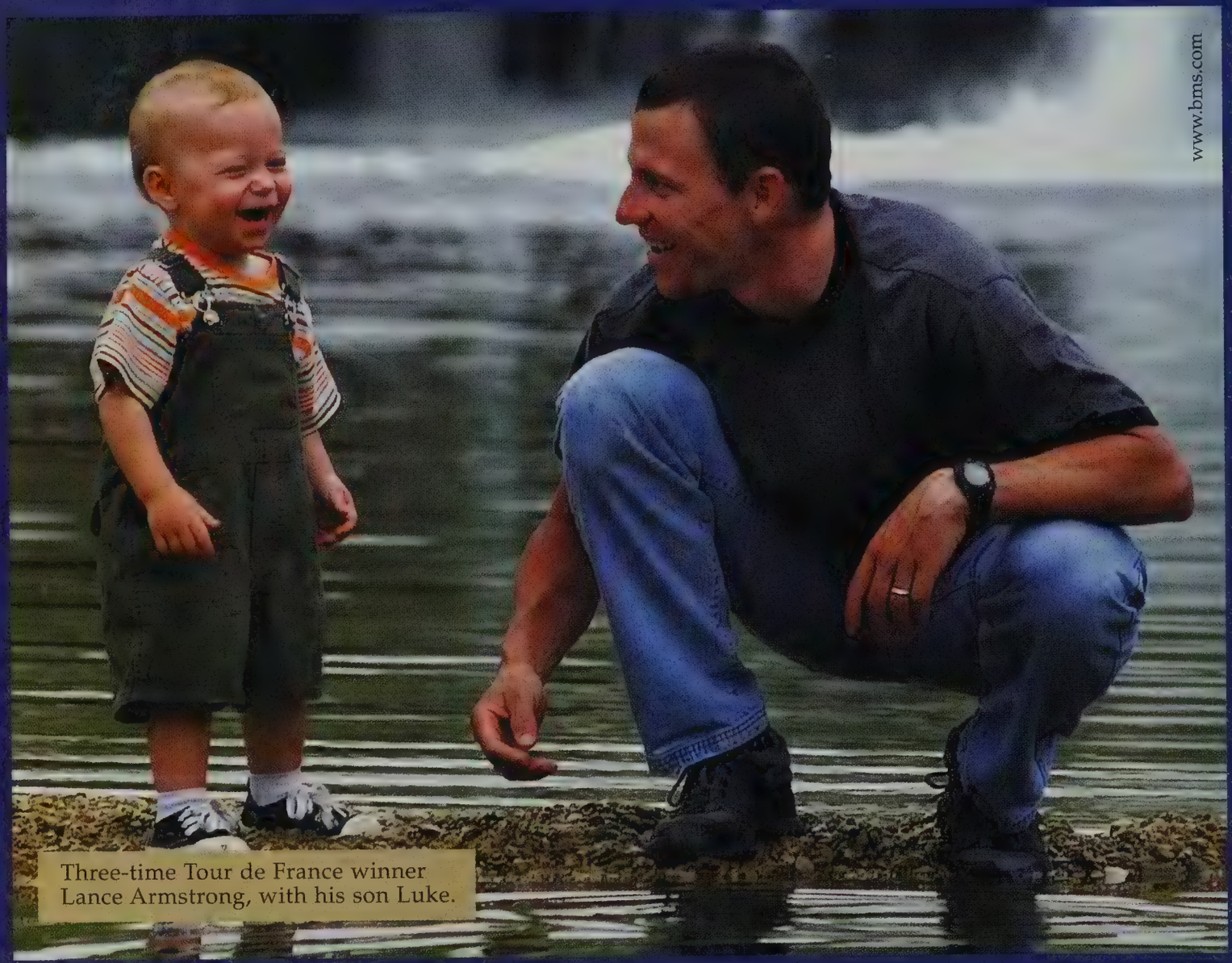

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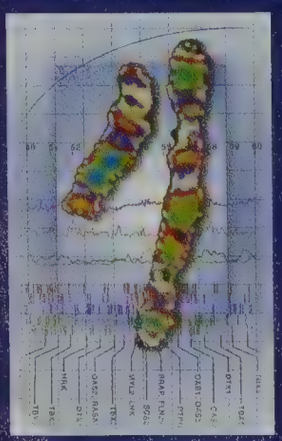
Three-time Tour de France winner Lance Armstrong, with his son Luke.



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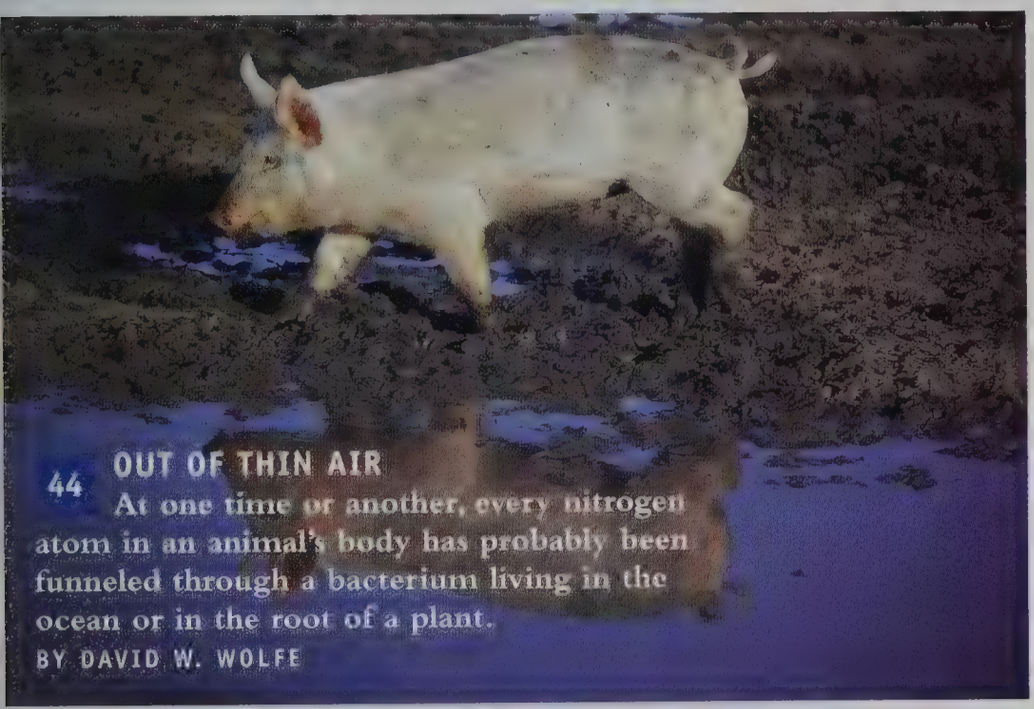
SEPTEMBER 2001 VOLUME 110 NUMBER 7

FEATURES



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At one time or another, every nitrogen atom in an animal's body has probably been funneled through a bacterium living in the ocean or in the root of a plant.

BY DAVID W. WOLFE

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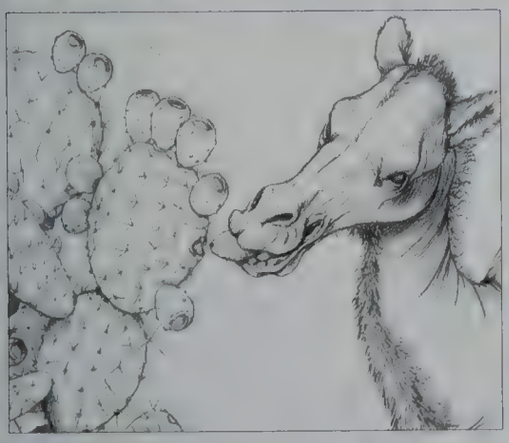
In Japan's Ryukyu archipelago, locally woven textiles connect the present with the past.

BY AMANDA MAYER STINCHECUM



62 GHOST STORIES FROM THE ICE AGE

Certain plants remind us that mastodons, camels, and ground sloths once chomped their way across America.

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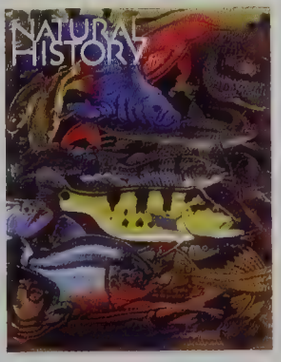
36 FRESHWATER RICHES OF THE AMAZON

When it comes to fish biodiversity, one river beats them all.

STORY BY JOHN LUNDBERG

PAINTING BY RAY TROLL



COVER

So far, scientists have identified more than two thousand species of fish in the Amazon River.

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PAINTING BY RAY TROLL

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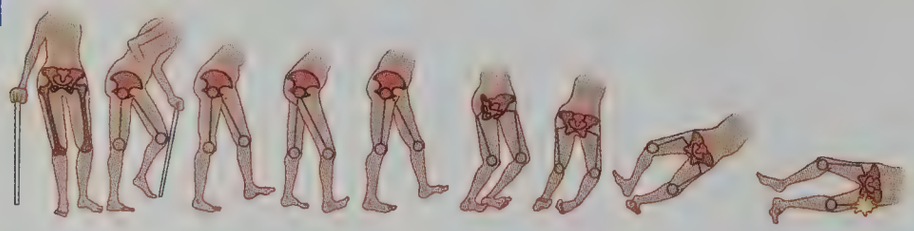

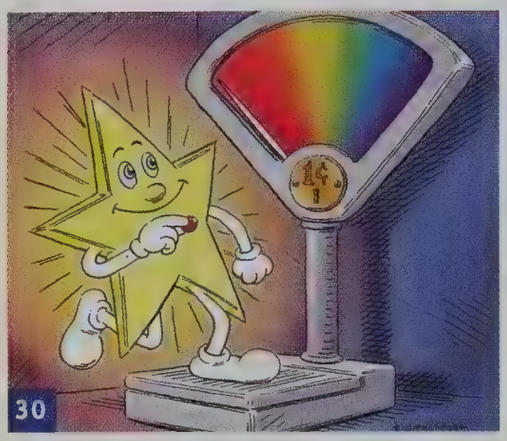

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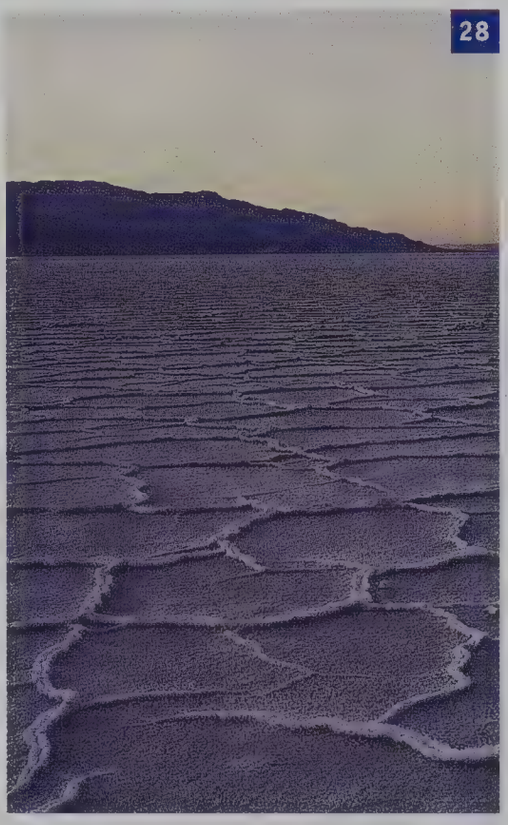

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UP FRONT

The Long View

Living on the paved island known as Manhattan, some of my encounters with nature necessarily take place on sidewalks. I once followed a giant silk moth for several blocks along Amsterdam Avenue in broad daylight. On a spring morning several years ago, I saw a tiny ovenbird that was walking north on Park Avenue, probably exhausted by its migratory flight from South America. And I routinely glimpse house mice frolicking in the median strip along upper Broadway after dark.

But most of my observations of plants and animals (not counting carpet beetles, silverfish, and cockroaches) take place in public parks and gardens. A favorite stroll in Riverside Park takes me past a row of honey locust trees. Long ago, I noticed that their trunks (beginning about eight feet above the ground) were encircled with three- to five-inch-long, needlelike thorns.

I'd never given the thorns a thought, however, until Connie Barlow, a writer and independent scholar of evolution, came to the magazine's office to propose a story on "anachronistic fruits." Barlow explained the intriguing idea that many puzzling features of North American plants—the huge pit of the avocado, the indigestible flesh of the Osage orange, the outrageous thorns of the honey locust—evolved as either enticements to or defenses against large animals that are now extinct.

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In 1925, excavations for an apartment building in northern Manhattan turned up a lower jaw, some teeth, and one limb bone from *Mammut americanum,* the American mastodon. For millions of years, until about 10,000 years ago, these elephants doubtless walked where I now walk in Riverside Park, and their appetite for the honey locust's seed pods may have had a role in the evolution of the tree's ferocious thorns.

Thinking about nature in evolutionary terms—a point of view that's common in the pages of a natural history magazine but rare in other venues—gives one a marvelously long view and some unusual insights into why things are the way they are. Once upon a time, ground sloths or camels or even ancestral rhinoceroses may have inhabited your part of the country. Reading Barlow's "Ghost Stories From the Ice Age" (page 62) makes one think about such things.—*Ellen Goldensohn*

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Ichthyologist **John Lundberg** ("Freshwater Riches of the Amazon," page 36) began studying the fishes of South America's Orinoco River in 1974 and those of the Amazon River in 1990. His pioneering surveys of the fish life of deep river channels have turned up many new species, including catfishes and electric fishes with unusual lifestyles. Lundberg, left, says his "innate attraction to fossils" has led him to broaden his focus; he uses insights from paleontology, geology, and biogeography in his work on tropical fish diversity. Formerly a professor at Duke University and the University of Arizona, Lundberg is now curator of ichthyology at the Academy of Natural Sciences in Philadelphia and holds adjunct professorships at the University of Pennsylvania and Drexel University. After an autumn 1997 trip down the Amazon with a boatful of friends and scientists, artist **Ray Troll** was inspired to produce his most ambitious work to date: a mural-sized canvas that took a year to complete and that portrays about 120 species—furred, feathered, but mostly finned. Troll lives in Ketchikan, Alaska, but travels frequently in the service of art and fish. He and writer Brad Matsen have produced various books on their adventures with fish, both fossil and modern. Troll is currently completing a book on sharks. For an out-of-the-ordinary fish-viewing experience, look at www.trollart.com.

David W. Wolfe ("Out of Thin Air," page 44) reports that inspiration for his recent book, *Tales From the Underground: A Natural History of Subterranean Life* (Perseus Books, 2001), often came while poking around in the dirt on daily hikes with his dog in upstate New York. But Wolfe's interest in the soil has its roots in central New Mexico, where he spent many childhood hours uncovering subterranean ant colonies in the dusty mesas near his home. Once his parents gave him a microscope, he says, "there was no turning back." An associate professor of plant ecology in the Department of Horticulture at Cornell University, Wolfe now gets paid for digging in the dirt. His current research subjects include a common root fungus that helps plants take up nitrogen more efficiently, methods for reducing the use of synthetic nitrogen fertilizers on farms, and the effects of elevated levels of atmospheric CO_2 on symbiotic nitrogen fixation in legumes. When he needs a break from the soil, Wolfe grabs his scuba gear and heads for the water. "Surface life," he says, "just seems so ordinary compared with these environments."

An independent scholar and freelance writer, **Amanda Mayer Stinchecum** ("Threads of Okinawan History," page 54) has researched the craft and history of textiles in the Ryukyu Islands for more than fifteen years, most recently as a Japan Foundation Fellow engaged in fieldwork on Taketomi, an island near the southwestern end of Okinawa Prefecture. Her particular interests include the ikat technique of creating dyed patterns as well as the methods of identifying plant fibers used in premodern cloths. Based in Brooklyn, New York, Stinchecum (shown here in 1985 examining fiber banana plants with *Mainichi* newspaper photographer Azuma Yasuo) has spent long periods in Japan. She was able to draw on her experience of the changing seasons there to write two previous *Natural History* articles: "Enduring Cold the Japanese Way" (October 1981) and "Cool Illusions in the Land of the Rising Sun" (August 1993).

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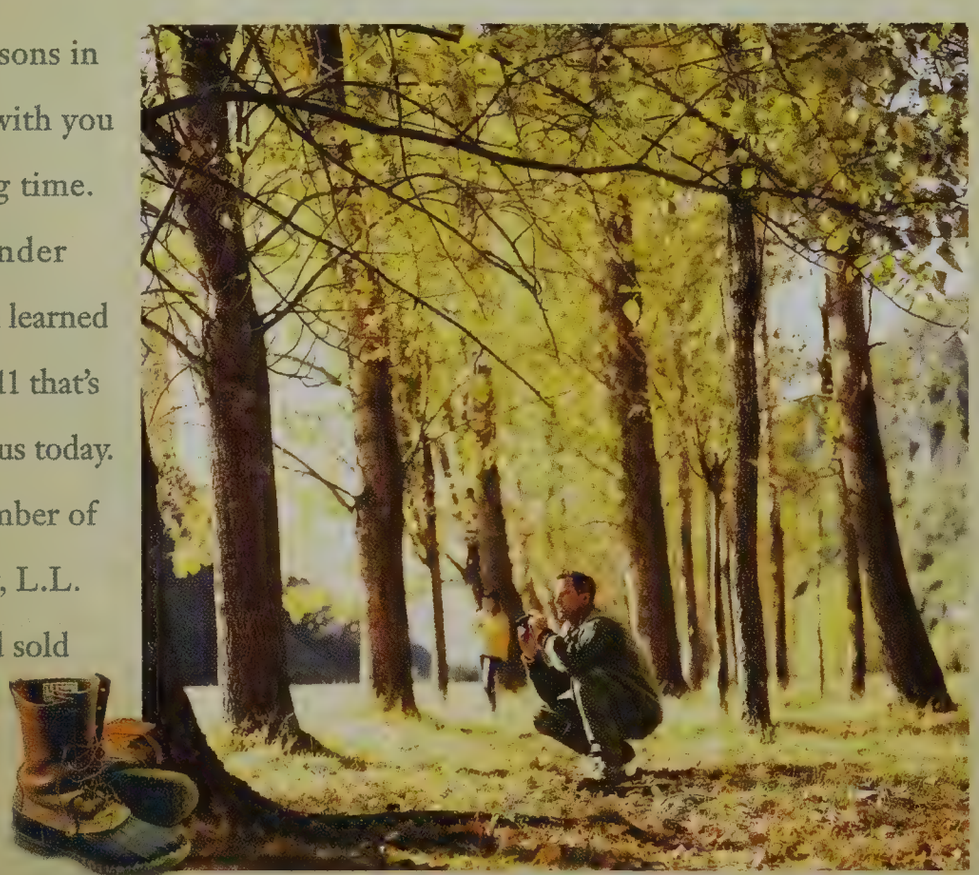

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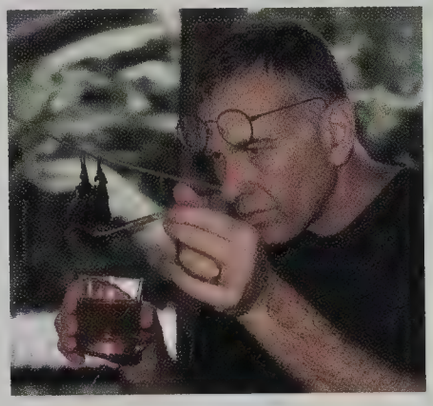
Connie Barlow ("Ghost Stories From the Ice Age," page 62), a science writer and amateur naturalist who was raised in Detroit, has spent much of her adult life living near wilderness areas in Alaska and New Mexico. She says that while working on her most recent book, *The Ghosts of Evolution* (Basic Books, 2001), she began to see "ghosts" everywhere—evidence of the lost mammalian megafauna of North America. With paleoecologist Paul Martin, she is promoting the reintroduction of elephants to grasslands in the U.S. Southwest, where the proliferation of shrubs is a problem. They believe the presence of these proboscideans would restore the balance that existed in Pleistocene times between grazers and large browsers. Barlow has long been interested in the implications of evolution for philosophy, ethics, and the understanding of humanity's role in the cosmos, as well as in the expression of the epic of evolution through art, literature, and celebratory events. She is the editor of *Evolution Extended: Biological Debates on the Meaning of Life* (MIT Press, 1994). **Michael Rothman,** who sketched the ghost species for Barlow's piece, has participated in expeditions to Western Samoa, French Guiana, and the Amazon River in Brazil (among other destinations), where he painted and photographed plants and animals. He has worked on several fossil reconstruction projects and has also illustrated fifteen science books for young readers. Rothman's artwork can be seen at zoos in Atlanta, Detroit, and Philadelphia. His natural-science illustrations have appeared in such publications as the *New York Times* and *Scientific American*, and he regularly illustrates articles for *Natural History* (see "Bats, Bees, and Brazil Nut Trees," April 2000, and "Undertakers of the Deep," November 1999).



Hiroshi Ogawa ("The Natural Moment," page 84) still lives in the small town in Japan's Ibaraki Prefecture where he was born in 1947. As a child, he says, "insects became my toys and my friends." Upon graduating from junior high school, Ogawa joined his father's roofing business. His passion for the past twenty-three years, however, has been photographing the insects of his native countryside. Self-taught in macrophotography and entomology, Ogawa specializes in documenting the social life of ants, wasps, and bees. His photographs have appeared in textbooks and encyclopedias, and one was featured on the March 2001 cover of *Natural History*. He has published more than thirty children's books; among those available in English are *Wasps* (text by Sylvia Johnson; Lerner Publications, 1984) and *The Potter Wasp* (edited by Kathleen Pohl; Raintree Publishers, 1986). Ogawa still climbs on roofs occasionally to photograph insects.

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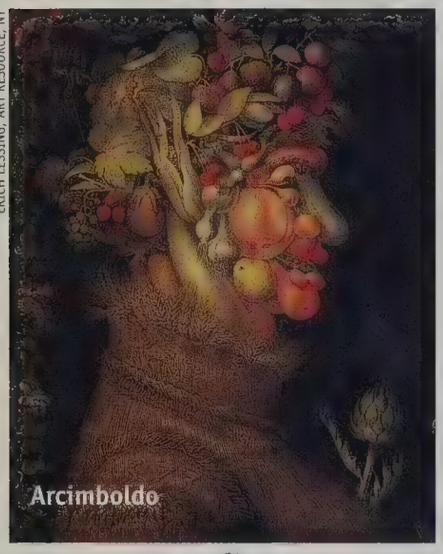
LETTERS

Family Resemblance?

The artist Alexis Rockman (cover, 6/01) must have taken inspiration from the work of Giuseppe Arcimboldo (1527–93), whose masterful conglomerations of ordinary objects, living and inanimate, are marvels. Had Arcimboldo been a contemporary of seventeenth-century scientist Robert Hooke or microscopist Antonie van Leeuwenhoek, he might have created a work similar to Rockman's.

Paul E. Hargraves
Narragansett, Rhode Island

ERICH LESSING; ART RESOURCE, NY



Arcimboldo

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Buonanni

NATURAL HISTORY

Rockman

Rockman may have been influenced by seventeenth-century images composed of seashells, sometimes with other marine forms and imaginary items. I enclose one of six such arrangements from Filippo Buonanni's 1681 work on mollusks.

Richard E. Petit
North Myrtle Beach, South Carolina

ALEXIS ROCKMAN REPLIES: I did have Giuseppe Arcimboldo in mind when I created the June cover, a "portrait" composed of bacteria and mitochondria. But while Arcimboldo employed familiar vegetable forms in his paintings, I used lesser-known organic elements that are actually found in the human body.

Now Hear This

In "The Lobster's Violin" ("Biomechanics," 6/01), Adam Summers describes the lobster's unusual means of sound production. He also compares the mechanism with that of insects that use friction (stridulation) to create sound. He cites both crickets and cicadas. However, cicadas produce their sounds—the loudest of any insects'—not by stridulation but by vibrating membranes, or tymbals, located on their abdomens. The pulses making up the cicada's sounds are analogous to the clicking that results when a rounded tin can lid is pushed in with a finger and then released—that is, two clicks per in-and-out cycle.

Jerome Rovner
Athens, Ohio

ADAM SUMMERS REPLIES: Jerome Rovner is correct, although the cicada's is a percussive, rather than a "stick-and-slip," sound. It won't work if the cuticle is soft.

Taste Test

One sunny July day in northern Wisconsin, my wife, daughter, and I were packing up our camping gear, which was soggy from a deluge the night before. When we paused and looked around, we beheld a surrealistic scene: down the dirt road were thousands, maybe tens of thousands, of butterflies. I believe they were mostly Harris's checkerspots and wood nymphs, or the like, but there were also the occasional monarchs, swallowtails, and mourning cloaks.

Many rose from the wet, bare patches of gravel left where the snowplow had dug down a little too deep the previous winter. But when it came to density of butterflies per inch, nothing beat out coyote scats. As we drove the few miles of bad road, we passed by lots of droppings, and every time we did, a heavy cloud of butterflies greeted us. I thought of them years later when I was covered in sweat during a cabin-building spree, and a couple of wood nymphs kept landing on my nose for a drink. Phil Schappert's "Butterfly Buffet" (7/01–8/01) made me wonder how I measured up as a meal. Was I tasty, or just a poor substitute for coyote waste?

Daniel Ryskamp
Kalamazoo, Michigan

In Texas for a period of time, whenever my brother would go out into his yard, a butterfly would repeatedly zoom at his head. The purpose of this strange activity later became clear to me. I had parked in my damp, unpaved driveway in Connecticut, and when I got out, a butterfly gave me the same treatment. Suspecting what was wanted, I moved the car. The insect landed on the mud where the vehicle had been and began to sip.

Fowler F. White
via e-mail

Natural History's e-mail address is nhmag@amnh.org.

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THE EVOLUTIONARY FRONT

Tuning In

At the genetic level, the signs of natural selection are surprisingly subtle.

By Carl Zimmer

More knowledge doesn't necessarily translate into less confusion. In 1953, when James Watson and Francis Crick discovered the double-helix structure of DNA, biologists were poised for all the pieces of evolutionary theory to fall quickly into place. Darwin had shown how natural selection could transform anatomy and patterns of behavior, and now scientists looked forward to detecting the fingerprints of natural selection at the molecular level. But it turned out that natural selection was not the only force that could significantly alter DNA, and no one knew how to identify the source of any given change. It has taken decades to figure out a way.

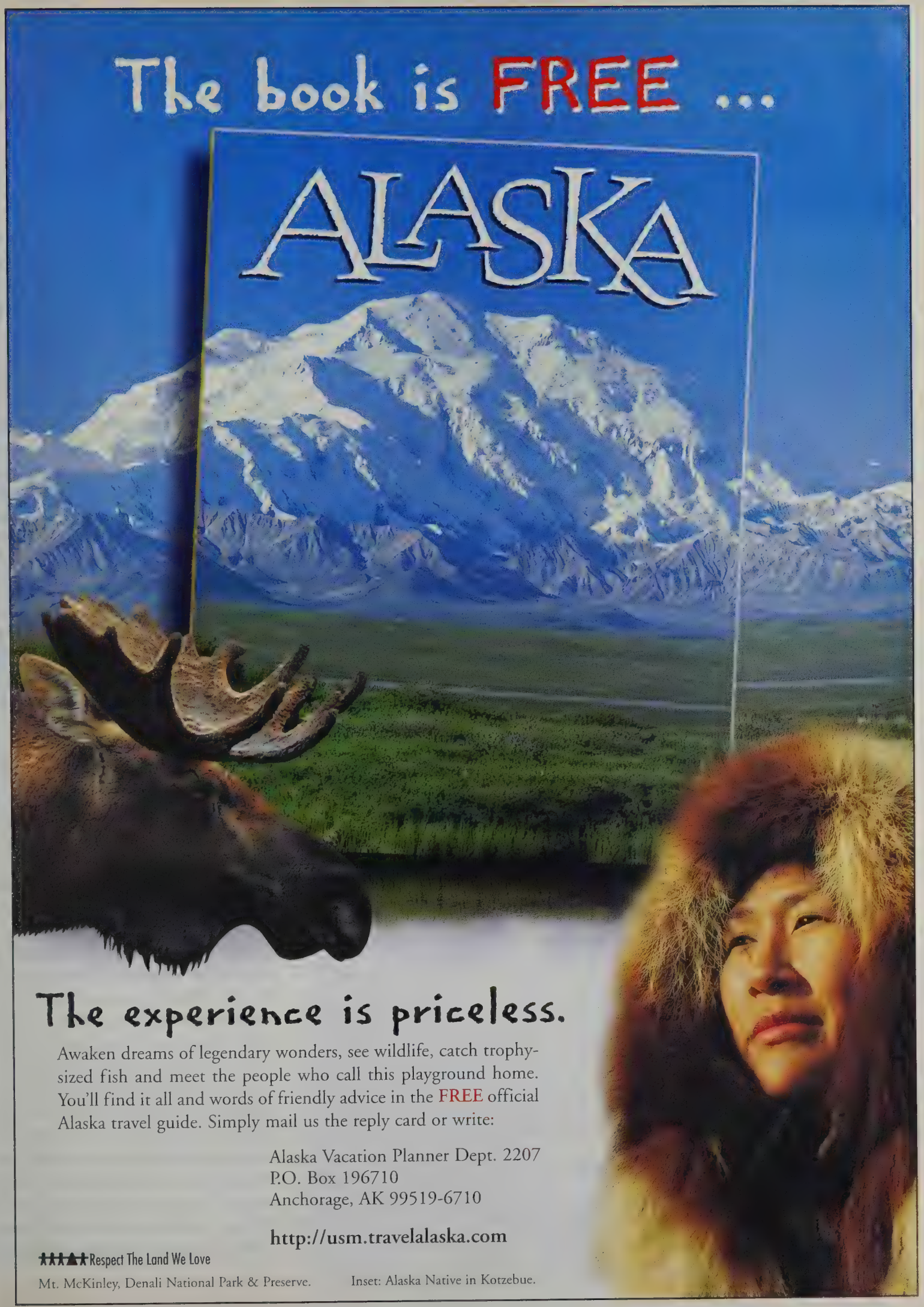
This predicament took many biologists by surprise, because once the structure of DNA was understood, they thought they had a good handle on how natural selection works. Researchers determined that a gene consists of a stretch of DNA—a sequence of molecules called nucleotides that serves as a blueprint for the synthesis of a protein. If the nucleotide sequence somehow mutates, it may produce a different protein. The new protein may turn out to be so defective that the individuals who inherit the mutation die or become infertile; either way, such harmful mutations may end up being almost completely weeded out of a species. But some mutations may give their owners a reproductive edge, and before long those mutations will become widespread—even universal—in a species. In the course of thousands and millions of years, a series of such beneficial changes could thus rework the genome of a species.

By the 1960s, however, researchers had realized that this was far from the whole story of evolution. Richard Lewontin, of Harvard University, and his colleagues collected fruit fly proteins and tallied the many variant forms of each. (The technology for sequencing the actual nucleotides was still two decades away.) They studied a selection of proteins in a single population of flies and found that fully 30 percent of the molecules existed in more than one form. If natural selection was weeding out mutations, then it was an awfully careless gardener.

Lewontin's research, and similar results from other scientists, led the Japanese biologist Motoo Kimura to launch a full-blown assault on the standard picture of how nucleotides evolve. Yes, he argued, some mutations were harmful and some were advantageous. But between those two extremes was a huge range of mutations that had no effect at all. Over the generations, these neutral mutations, as they came to be known, might become more common solely as a result of random fluctuations (a process called neutral evolution). Kimura predicted that most variation in DNA would turn out to be produced by neutral evolution and not by natural selection.

The irony was inescapable: scientists finally had a chance to tune in to evolution on its most basic level, but the signal of natural selection seemed to be swamped by the static of neutral evolution. If your radio can't pick up a clear signal, however, maybe what you need to do is build a better radio. And biologists set out to do just that. By the 1970s, researchers had realized that there was a way—at least in theory—to isolate the signal of natural selection, thanks to the way cells build proteins.

A cell makes a copy of a gene's sequence and then ships this code out to a protein-building factory called a ribosome. There the genetic code acts as a guide for building a protein out of a set of molecules called amino acids. But a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Inset: Alaska Native in Kotzebue.

gene's nucleotides don't correspond to the sequence of amino acids in the protein in a one-to-one fashion. Before adding an amino acid to the end of a protein under construction, ribosomes have to read three nucleotides in a row. And in many cases, different trios of nucleotides can direct a ribosome to add the same amino acid. For example, if the nucleotide guanine appears three times in a row, a ribosome adds the amino acid glycine to the protein it is building. But it will add glycine even if the genetic sequence reads "guanine-guanine-thymine."

So imagine that a gene whose sequence includes three guanines mutates, with the third guanine turning into thymine. Even though the gene has changed, it still calls for the same old glycine. The new protein will not just be similar to the old one; it will be identical. Geneticists call these kinds of mutations "silent substitutions," as opposed to "replacement substitutions," which actually change the structure of a protein.

A comparison of the numbers of silent and replacement substitutions acquired by a gene should reveal whether it has experienced natural selection. Genes mutate randomly—both at sites where silent mutations occur and at replacement sites. If they are evolving neutrally, both kinds of mutations are equally likely to become universal. In other words, if 1 percent of the silent sites change in a million years, so will 1 percent of the replacement sites. But natural selection favors certain replacement mutations and makes them spread faster than neutral evolution can. Mutations that change a protein to some superior version will accumulate more quickly than will silent substitutions. If, say, 1 percent of the silent sites in a gene change in 10 million years, natural selection might in fact change 5 percent of the replacement sites.

In theory, then, it should be simple to check a gene for natural selection. All you'd have to do is tally the fraction of replacement sites that have mutated and compare that with the fraction of silent sites. If the ratio is one to one, the gene has evolved neutrally. If the ratio is higher, natural selection has been at work. And the higher the ratio, the more intense the natural selection.

While simple in concept, this evolutionary "radio" was actually staggeringly hard to build. For one thing, researchers can't go back millions of years to read a gene's ancestral sequence, nor can they know the precise history of mutations that led up to its current form. But biologists can make some inferences by comparing the genes of closely related animals. Imagine, for example, that a certain gene for red blood cells is identical in every ape but that the human version of the gene differs at the 123rd position. It would be a safe bet that the human gene started off like the others and later mutated at position 123. But the evidence from real genes is rarely so clean, and thus some uncertainty inevitably creeps in.

Making matters fuzzier, until only a few years ago biologists had relatively few genetic sequences available to analyze. Like a political poll of your four best friends, studies of these genes were usually not statistically significant. Another problem was that the models of evolution used by biologists for detecting natural selection assumed that mutations were random, which is not entirely true. For example, the chemical nature of DNA makes certain nucleotides more likely to mutate into certain other ones. With so much uncertainty in their methods, biologists attempting to tune in to natural selection couldn't be sure they weren't getting a false signal.

Not until the mid-1990s were researchers able to sidestep these uncertainties. By then, genetic data banks had begun to swell with sequences, and computers were becoming outrageously fast. Taking advantage of both trends, researchers began analyzing DNA using powerful statistical equations. One of the most widely used methods is called maximum likelihood. Although there's some head-spinning math behind the procedure, it basically works this way: First, pick a group of related species you want to study. Then compare various chunks of their DNA to determine their relationships and build their evolutionary tree. Now choose a gene whose history you want to track along the branches of the tree.

> Yes, some mutations are harmful and some are advantageous. But between these two extremes is a huge range of mutations that have no effect at all.

Ziheng Yang, of University College London, and his colleagues have led the way in this approach. They program computers to look at every possible series of mutations that could have yielded the existing variants of a gene from a common ancestor. By sorting through the billions of possible scenarios and calculating the effects of different degrees of natural selection, the computer finds the level of natural selection that offers the maximum likelihood of having produced the actual gene sequences.

Other researchers are using methods such as Yang's to analyze hundreds of genes from numerous species, including humans. Many of these genes indeed turn out to be evolving neutrally, just as Kimura predicted they would. But some glow with natural selection's fire. The genes for some of the immune-system proteins that recognize invading pathogens have been adapting particularly quickly. Known as the major histocompatibility complex (MHC), these proteins are found within each cell, and their job is to lock

on to fragments of viruses and other parasites within the cell and bring them to the cell's surface. Special immune-system cells passing by can recognize the fragments so displayed and force the infected cell to self-destruct. It turns out that some genes that build MHC proteins have acquired four times more replacement mutations than silent ones.

Scientists can tune in even more precisely to natural selection—determining not just whether a gene has been affected by it but which of its individual nucleotides has. Using the maximum likelihood method, for instance, Yang examines each site in a gene and tries to predict its nucleotide on the basis of the rest of the gene's sequence as well as the sequence of the gene in related species. The computer makes a series of predictions based on different assumptions about the level of natural selection acting on the site and then picks the level that works best.

Apparently, only a few nucleotides in MHC genes have been strongly affected by natural selection. If you look at their positions, they seem to be scattered randomly here and there within the gene. But the hidden order becomes apparent once you take account of the actual shape of MHC proteins. All the amino acids altered by natural selection are found at a cleft in the proteins—the place where they actually make contact with the pathogens.

Researchers had anticipated exactly these results, basing their prediction on the struggle between hosts and parasites. If a pathogen evolves a new structure, an old MHC protein may be less capable of grabbing onto it, making it harder for the host to fight off the disease. As a result, natural selection should favor animals with new MHC proteins that offer a better grip. Not surprisingly, researchers have also found signs of intense natural selection in the genes that construct the surface proteins of bacteria and viruses. The changes in their structure enable the pathogens to evade recognition by the immune system.

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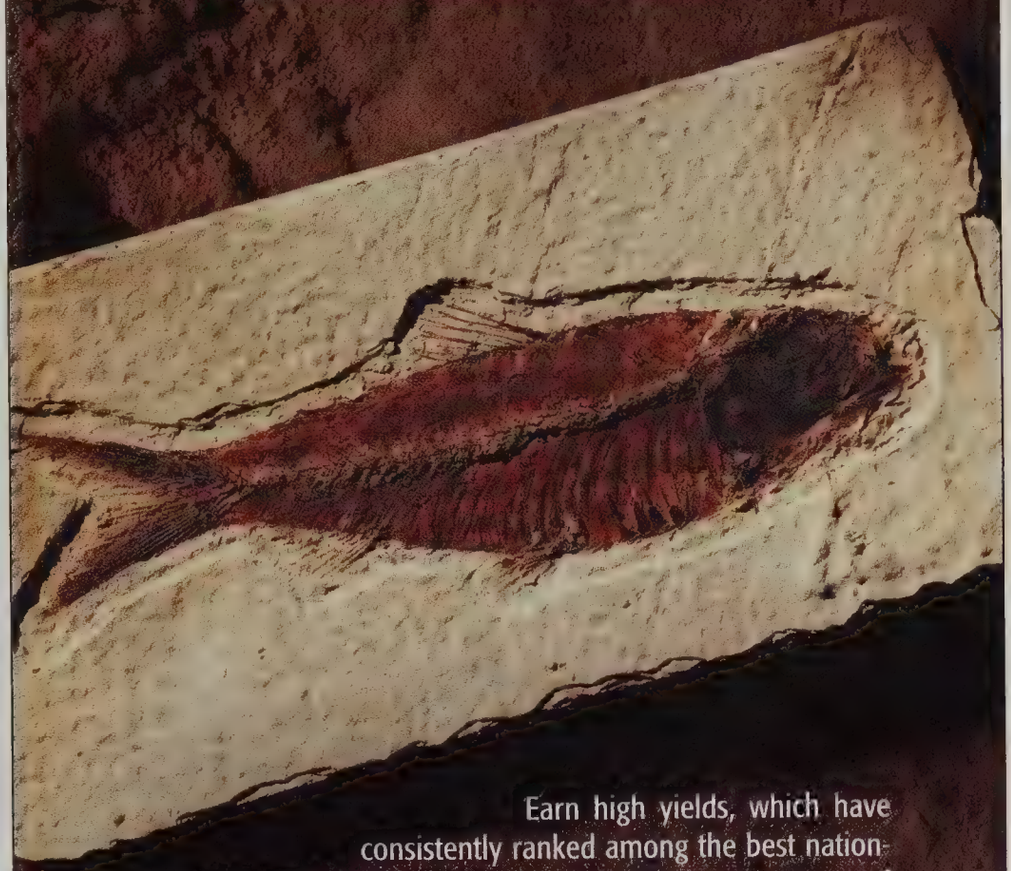

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Through studying these hot spots of adaptation in disease genes, scientists may be able to make new vaccines to keep up with their evolution.

When scientists began to tune in to natural selection, they also expected to hear a loud signal coming from the genes involved in sex. Biologists knew from studies on a wide range of animals that males compete with other males to fertilize eggs and that females choose potential mates based on the males' appearance and, perhaps, even on their sperm. Last year Gerald Wyckoff, Wen Wang, and Chung-I Wu, of the University of Chicago, discovered that a few genes that help build sperm in humans were undergoing rapid selection. And last February, Willie Swanson and his colleagues at Cornell University teamed up with Ziheng Yang; together they detected equally strong selection at work on genes that build the proteins on the surface of human egg cells. As was the case with the MHC, they found that natural selection was at work on only a few nucleotides—specifically, the ones that build part of the protein that makes contact with the head of a fertilizing sperm.

These biologists have only pointed to the regions where natural selection is taking place; they don't yet know exactly what adaptive pressures are driving it. One possibility is that receptors on the eggs enable them to choose certain sperm for fertilization. As male genes for the surface of sperm adapt to these receptors, the female genes for eggs evolve into new forms.

When we think of what changes in our ancestors gave rise to *Homo sapiens,* the genetics of fertilization and head colds may not pop to the top of the list. The only reason that genes involved in sex and sickness were the first to reveal evidence of natural selection is simply that biologists turned to them first. Researchers are now looking for evidence of natural selection in other kinds of genes. One of the most surprising results of this search came in August 2000 from Gavin Huttley, a geneticist at Australian National University. Huttley has discovered that a gene called *BRCA1* has experienced strong natural selection over the past few million years.

BRCA1 has been in the news in recent years because it sometimes mutates into a form that has been linked to several types of cancer, such as breast and prostate cancers. Normally, the gene plays vital roles in the development of embryos and the repair of damaged DNA. Huttley compared the *BRCA1* gene in humans with those in other apes and discovered that it experienced intense natural selection in our ancestors. It's possible, he concludes, that the cancers *BRCA1* can cause when it mutates are a price we pay for having become human.

Other genes may have evolved in important ways, too, but natural selection may have affected only a few key mutations, making them hard to detect. Wyckoff, Wu, and their University of Chicago colleague Justin Fay predict that many such genes will be discovered. In the July 2001 issue of *Genetics,* they reported on a survey they had made of several hundred genes sequenced during the Human Genome Project. Rather than analyzing individual genes, they pooled all of them together and compared them with the same sequences in other primates. By analyzing so much data at once, they hoped to pick up faint signals of natural selection that they might otherwise have missed in any single gene. The scientists were not disappointed. In the 30 million years since our ancestors split from those of the Old World monkeys, more than a third of the changes in our amino acids have been the result of natural selection. Wyckoff, Wu, and Fay calculate that, on average, one of these adaptive changes happened every eighty years or so.

Natural selection is widespread in the human genome; now biologists just have to figure out exactly which genes have experienced it. Not surprisingly, researchers such as Wyckoff and his coworkers (notably graduate student Steve Dorns, who works at the laboratory of Bruce Lahn, of the University of Chicago and Howard Hughes Medical Institute) are examining the genes that help build and operate the human brain. After all, the human brain is in some ways very different from those of apes. The most obvious difference is size: relative to body weight, a human brain is twice as big as a chimp brain.

The initial results are telling—but not what you might expect. In the few brain-related genes that scientists have closely studied in primates, silent substitutions far outnumber replacement substitutions. This sort of ratio is the sign of a third kind of evolution, known as purifying selection. Some particularly intricate parts of the body cannot tolerate even a little tinkering with their structure, so any change to the proteins involved gets ruthlessly weeded out. The primate brain may be one such delicately constructed organ.

> In humans, the *BRCA1* gene can mutate into a form linked to cancer. This risk may be a price we pay for having evolved separately from the apes.

Ancestral humans somehow overcame this resistance to change and acquired a few precious mutations that made them (and us) particularly clever. But finding a way to detect those crucial changes may prove to be one of our greatest mental challenges.

Science writer Carl Zimmer is the author of Evolution: The Triumph of an Idea *(HarperCollins, 2001). His book* Parasite Rex *has just been published in paperback.*

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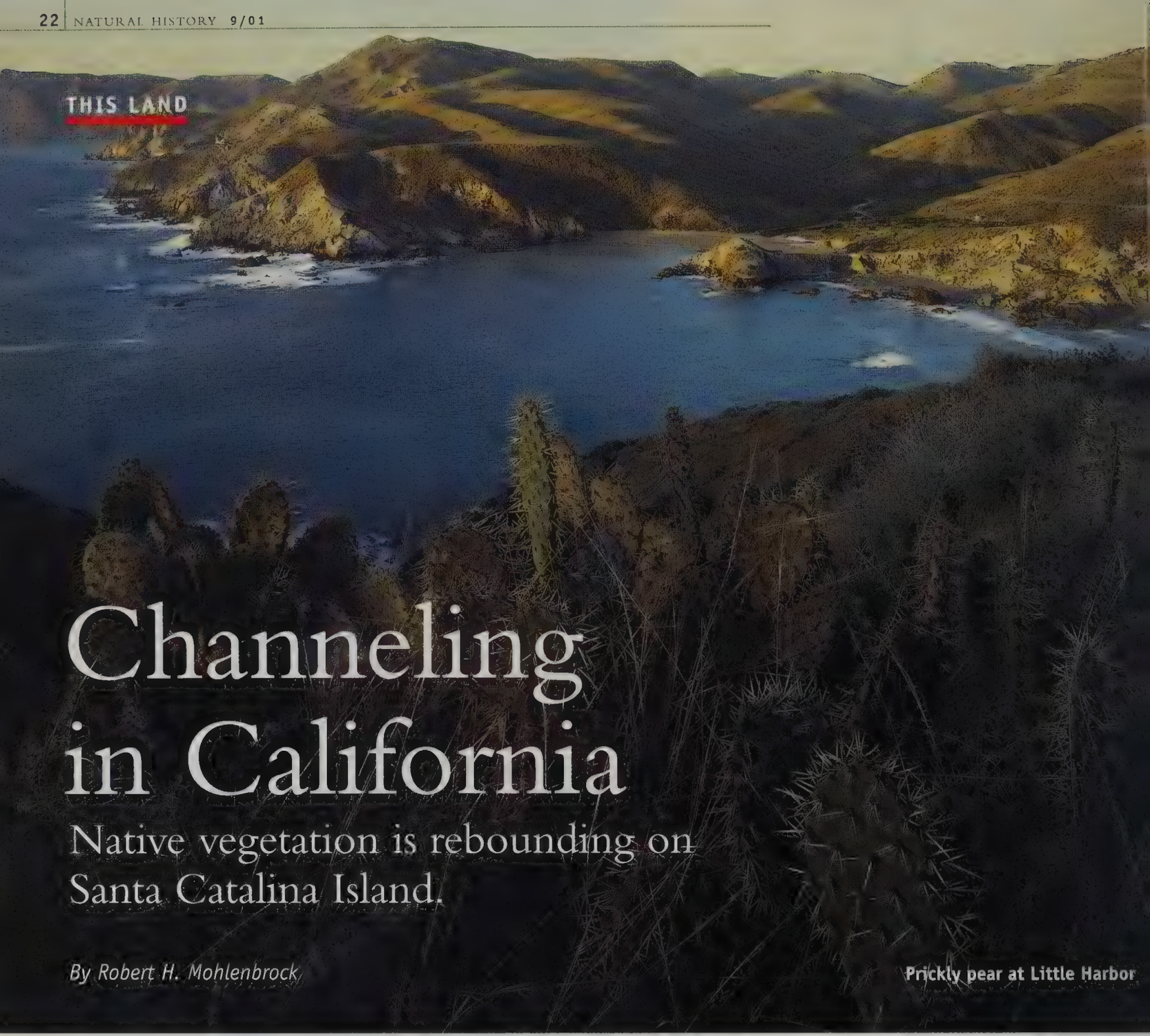
THIS LAND

Channeling in California

Native vegetation is rebounding on Santa Catalina Island.

By Robert H. Mohlenbrock



Prickly pear at Little Harbor

A dense fog hung over the Gulf of Santa Catalina as my wife, Beverly, and I boarded a high-speed boat at Dana Point, not far from the famous Mission San Juan Capistrano, southeast of Los Angeles. It took just an hour and a half to cross the thirty-five miles that separated the mainland from our destination, Santa Catalina Island. Covering seventy-six square miles, Santa Catalina is one of southern California's eight Channel Islands. Five others—San Miguel, Santa Rosa, Santa Cruz, Anacapa, and Santa Barbara—constitute Channel Islands National Park. The remaining two are San Nicolas and San Clemente.

The Channel Islands (often called the Santa Barbara Islands) began emerging above sea level about 5 million years ago as volcanic, igneous, sedimentary, and metamorphic rocks were uplifted by tectonic forces associated with the San Andreas Fault. Some, including Santa Catalina, were also overlain by lava flows. During the last glaciation, when sea levels were roughly 400 feet lower, a few of the islands were connected to each other, but all of them have always been isolated from the mainland. As a result, each hosts a variety of endemic plants and animals—that is, species or subspecies found only there.

Santa Catalina is twenty-two miles long and ranges in width from half a mile, at an isthmus, to eight miles. It is essentially a mountain ridge, the highest point being 2,097-foot Mount Orizaba. Along the coast, precipitous cliffs up to 1,400 feet high are interspersed with coves and bays leading into deep, V-shaped canyons. Most of the beaches in the coves are

JEFF GNASS

covered with cobblestones, while a few are sandy. Summers are warm and dry: most of the annual rainfall of twelve or more inches falls during the winter. Although the Santa Ana winds that blow from the mainland in winter are often violent, temperatures remain mild.

The original vegetation of Santa Catalina Island has been altered by human activity, particularly through the introduction, more than a century ago, of sheep, goats, and cattle, followed by mule deer, wild pigs, and bison. After years of intense grazing, existing chaparral and coastal scrub communities were largely replaced by nonnative grasses. During the last half of the twentieth century, however, efforts were made to control feral goats and pigs and to remove some of the cattle and bison (only a small herd of bison now remains as a tourist attraction). Today, 88 percent of the island is owned by the Santa Catalina Island Conservancy, which was formed in 1972, and the original vegetation is gradually being renewed.

The habitats include oak woodland, riparian woodland, chaparral, coastal scrub, bluff faces, maritime desert scrub, grasslands, and marshy areas and ponds. About 640 plant species have been recorded on Santa Catalina, nearly two-thirds of them native. Most of the native plants can also be found in the Santa Monica Mountains on the mainland, but several are restricted to the Channel Islands or just to Santa Catalina. Some of the rarest plants live on steep rocky cliffs that have been inaccessible to the island's feral goats.

A California quail and a Bewick's wren are among four bird subspecies found only on Santa Catalina. Native mammals include five endemic subspecies, the largest of which is a Channel Island fox. There are also various endemic invertebrates, including two snails, several butterflies and moths, a few beetles, a cricket, and a walking stick.

Robert H. Mohlenbrock, professor emeritus of plant biology at Southern Illinois University, Carbondale, explores the biological and geological highlights of U.S. national forests and other parklands.

HABITATS

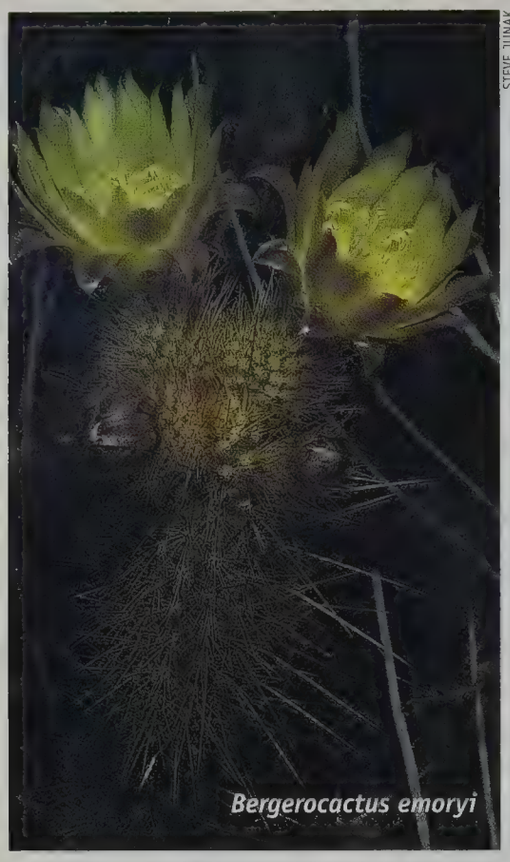
Oak woodland develops best in moist, protected canyons and valleys with deep alluvial soils. Island oak, canyon oak, and scrub oak are common, along with Catalina cherry, elderberry, and summer holly (actually a member of the heath family). The rare Catalina ironwood is found in Toyon Canyon and in a few other canyons. Wildflowers include miner's lettuce, lacepod, a buttercup, and the showy fiesta flower (a member of the same family as waterleaf). Among the ferns are California polypody, maidenhair fern, and golden-back fern.

Riparian woodland, with black cottonwood and Fremont cottonwood as the major trees, grows along the streams of canyon floors. Red willow, arroyo willow, elderberry, and McDonald oak are present in the tree and shrub layers. Low-growing shrubs include wild rose, California blackberry, and snowberry. Wild honeysuckle, wild grape, redroot (a type of wild cucumber), and coral vine climb over the vegetation. Purple vervain is one of the few colorful wildflowers.

Chaparral is found on north- and east-facing slopes on the side of the island facing the mainland and also in arroyos (dry gullies that carry water after a rain) on the Pacific slopes. One of the best of these sparsely vegetated, shrubby habitats is found on the western slopes of Black Jack Mountain. Among the shrubby species are a tree poppy, three kinds of sumacs (lemonade, laurel sumac, and sugar sumac), chamise, island buckthorn, mountain mahogany, Christmas berry (toyon), pitcher sage, wild apple (which is not an apple, despite the similar appearance of the fruit), and Santa Catalina and white lilacs (not really lilacs but relatives of the New Jersey tea of the eastern United States). An uncommon endemic on the slopes of Black Jack Mountain is Greene's rockrose. Of the few wildflowers, figwort and everlasting appear to be the most common.

STEPHEN P. PARKER; PHOTO RESEARCHERS, INC.

Coastal scrub appears on some of the canyon slopes where the soil is extremely thin and rocky. A good



STEVE JUNAK

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place to observe this open habitat is above the beach at Little Harbor, on the island's west side. California sagebrush dominates, although prickly pear, lemonade, laurel sumac, deerbrush, white sage, and black sage are common. St.-Catherine's-lace has huge clusters of white flowers on a stem that may reach twelve feet tall. A species of tree mallow attains a similar height.

Bluff face plants include the fleshy-stemmed sea dahlia; alabaster plant, a species with fleshy leaves; dusty-miller, with its gray leaves and stems; bush snapdragon; sticky monkey-flower; and snake's-head, a tall perennial in the aster family. Two species of live-forever (a succulent) grow from crevices in the steep cliffs.

Maritime desert scrub is the most arid of the island's habitats. It occurs on headlands, such as the southwestern side of Indian Head Point, that are exposed to prevailing westerly winds blowing in from the Pacific. Velvet cactus, prickly pear, *Bergerocactus emoryi*, and cholla are widespread, often joined by box thorn, a prickly shrub in the nightshade family. Other common plants are brittlebush, California sagebrush, several wildflowers in the aster family, and a wild four-o'clock.

Grassland areas have begun to see the return of some native species, including feather love grass and two kinds of needlegrass. In early spring, the grasslands are often covered with the shiny yellow heads of goldfields. Other wildflowers interspersed among the grasses are tidy tips, red maids, Indian paintbrush, owl's clover, shooting-star, larkspur, golden star, mariposa lily, and johnny-jump-up.

Freshwater marsh and aquatic plants can be seen throughout the year in Cottonwood Canyon and Bulrush Canyon. Among them are scouring rushes, brass-buttons, yerba mansa, watercress, camphorweed, two kinds of cattails, and a variety of sedges and rushes.

STEVE JUNAK

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IN SUM

FOWL CALLS Most of us think we're familiar with the sounds of the domestic chicken, *Gallus gallus domesticus,* but not all fowl calls are created equal. One distinctive sound, uttered by females only after egg laying and predictably named the postoviposition cackle, has long been something of a mystery to scientists.

Since the loud cackle can alert potential predators to a freshly laid egg, evolutionary biologists assume that the call must have a benefit outweighing the risk. Some have suggested that hens cackle to announce to roosters their renewed receptivity to mating.

ROBERT MAIER; ANIMALS ANIMALS

Biologists Tommaso Pizzari and Tim Birkhead, of the University of Sheffield in England, tested this hypothesis in a free-range population of *G.g. domesticus* that was fully habituated to humans. Besides observing the chickens' cackling-related behavior, the researchers exposed the roosters to tape recordings that alternated hens' postoviposition cackles with "contentment" calls.

Contrary to expectation, cackling was observed after only about 15 percent of egg laying episodes, and just one-third of the hens ever burst into cackles after laying. Moreover, females that cackled were no more likely to mate than were those that did not. During the tape-playing experiments, most males ignored both calls; the few that paid attention to the recordings were equally interested in both types of calls.

Pizzari and Birkhead concluded that cackling after egg laying does not signal female receptivity. Indeed, they suggest, exactly the opposite may be occurring: females may be signaling their lack of receptivity in order to avoid male harassment, which sometimes results in lethal injuries to the hens. An alternative explanation leaves males out of the equation altogether: females may cackle to communicate with one another, perhaps to synchronize egg laying. ("For Whom Does the Hen Cackle? The Function of Postoviposition Cackling," *Animal Behaviour* 61, 2001)—*Kirsten L. Weir*

EAGLES VS. TRAINS Thanks to cleaner air and water, ample food supplies, reclaimed habitats, and release/monitoring programs, the U.S. bald eagle population has soared since the bird was listed as a national endangered species a quarter century ago. In New York State alone—where an aggressive restoration program operates—the number of fledged young rose from fifteen in 1990 to seventy-one in 2000.

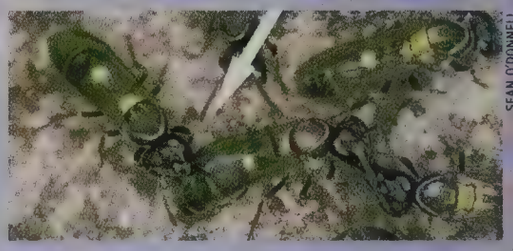
Many of the birds, which feed mainly on fish, winter or nest in the lower Hudson River valley. But this habitat has its perils, including passenger trains traveling at up to 125 miles an hour on the New York City–Montreal line. The high-speed trains make little noise and move faster than anything an eagle would encounter in its natural environment.

Ward B. Stone, of the New York State Department of Environmental Conservation, and colleagues examined ten eagles struck and killed by high-speed trains between 1986 and 2000. Most of these collisions occurred on the rail line between New York City and Albany, and nine of the ten eagles killed were immatures. Less wary and agile than adults, young eagles are more likely to scavenge and thus to be attracted to the ample supply of dead animals on the tracks.

Some observers have suggested that carrion on train tracks actually aids overall eagle survival by providing fledglings with a ready food supply. But Stone and colleagues conclude that, with several new nesting territories nearby, the trains' net effect on the eagle population "is most likely to be decidedly negative." ("Bald Eagles Killed by Trains in New York State," *Short Communications* 35:1, 2001)—*Heather Van Doren*

WASP BITES WASP Many types of colonial insects share information via body contact. One of the more mysterious forms of such contact is known as social biting, and species that engage in the practice don't necessarily restrict themselves to dainty nibbles. *Polybia occidentalis* wasps, for example, go at a nest mate's body with degrees of intensity that range from mildly chewing to mauling the victim and lifting it right into the air.

But exactly what message does such chomping send? To find out, Sean O'Donnell, of the University of Washington, Seattle, studied female *P. occidentalis* workers at a field site in Costa Rica. He first investigated whether sexual competition was involved; other studies have shown that female workers in some species, possibly responding to chemical cues, police one another's reproductive status by attacking those females with well-developed ovaries. (Evolutionary theory suggests that the group's best interests are served if the queen is the sole breeder.)


SEAN O'DONNELL

The researcher observed marked females to determine how often and how badly they bit or were bitten. He compared these stats with their size, their degree of ovary development, and the frequency of their departures for the foraging field.

O'Donnell found that female workers' biting behavior was not related to body size or degree of ovary development, so reproductive competition couldn't explain it. Foragers (usually the older wasps) were bitten more often than the younger wasps designated to work only in or on the nest. And bitten foragers were more likely to leave the nest immediately in search of food and supplies. O'Donnell concluded that biting encourages wasps to do their jobs, but the factors that determine a worker's social standing—that is, whether it is more likely to be the biter or the bitten—remain a mystery. ("Worker Biting Interactions and Task Performance in a Swarm-Founding Eusocial Wasp," *Behavioral Ecology* 12, 2001)—*Kirsten L. Weir*

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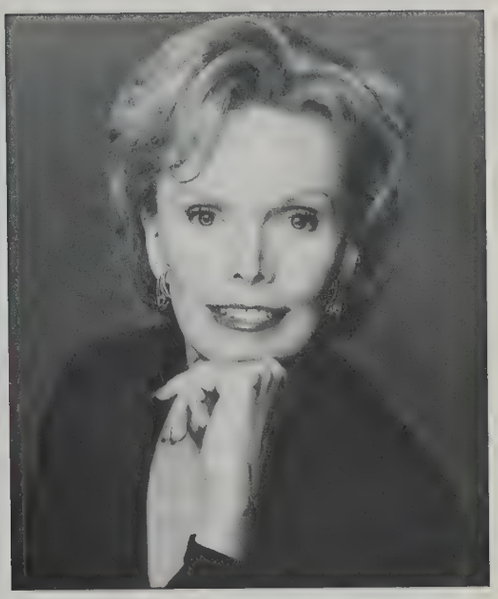

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IN THE FIELD

Salt of the Earth

Tiny mineral crystals can have huge effects on arid landscapes.

By Peter J. Marchand

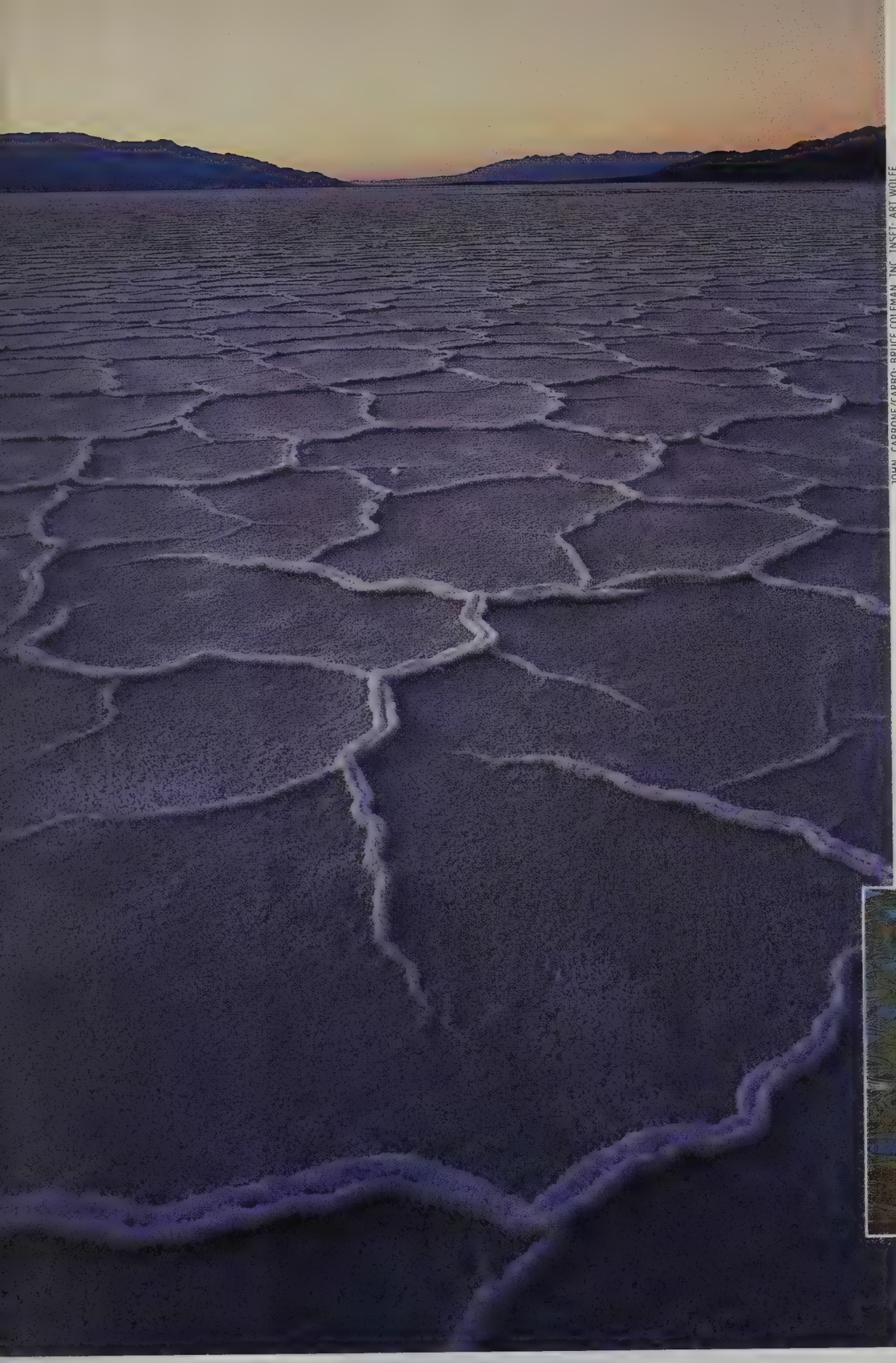
Badwater Basin, Death Valley, California. Squinting across the shimmering expanse of pure white salt, I was unprepared for what I saw. Etched into the surface of that mirror-flat basin was a netlike pattern of polygons bearing a remarkable resemblance to the ones I'd just seen in the frost-shaped landscape of northwestern Alaska. For a moment I imagined that the glittering white was snow and that the raised ridges defining the large polygons were ice wedges growing in cracked, frozen earth. I lifted my hat and wiped my brow, recalling stories of cruel delusion suffered by pioneers crossing the Mojave Desert in the searing heat. But the scene before me was no mirage.

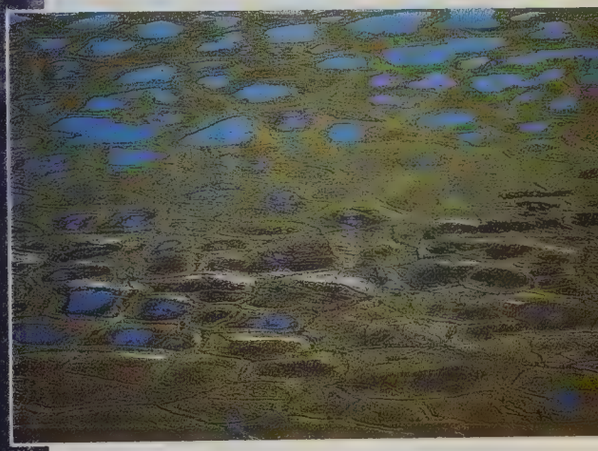
That two such disparate environments, at opposite ends of the climatic spectrum, should produce similar features surprised me at first. Yet patterned ground resembling that of northern polar regions can be seen in deserts as far afield as Egypt, Iran, China, Mongolia, and Peru. In the United States, such features show up sporadically in arid lands from New Mexico to Idaho. Nor is the resemblance superficial, for in both hot and cold climates the patterning results from the same fundamental process—the repeated expansion and contraction of the ground, often accompanied by the shifting and sorting of rocks. In the Arctic, extreme cold and freezing water are the principal agents, cracking the frozen earth beneath the surface and constantly churning, lifting, and moving the soil. In deserts, extreme heat and the crystallization of salts dissolved by percolating rainwater accomplish the same task.

Many streams in the world's arid and semiarid regions run only intermittently and empty into broad, undrained basins known as playas, where they deposit their sediment and dissolved minerals. As the water evaporates, a thick crust of salt crystals builds up on the surface. But salt formation is not limited to floodwater basins. Wherever salts are present in water, even in the moist soil beneath stones, they crystallize during dry spells. As these crystals grow, they exert considerable force, sometimes even raising stones on pedestals of salt. Crystals can also form within the minute pores of rocks exposed to saline water; straining against their confines, they may eventually break the rock apart. (I have seen evidence of this same destructive force in old fence posts driven into moist saline soils. Slowly, the salty water is drawn up through the wood, but as soon as it reaches ground level—where the wood is exposed to air and sunlight—the water evaporates and salt crystals form, shattering the post.)

Salt crystals generate additional stresses in fractured rock as they undergo daily cycles of heating and cooling. Warming by several degrees during the day, the crystals may expand at a faster rate than the minerals in the rock that contains them. Wedged into small cracks in granite, for instance, they may generate pressures of up to thirty pounds per square inch. And if they are dehydrated, they may enlarge even more as they attract water from the cool night air. Unlike dewdrops, which often sit on the surface of an object, water that attaches to salt actually becomes part of its crystalline structure and increases its volume. Like wet plaster of paris hardening in a glass jar, salt crystals that have incorporated water can also expand to crack their container. (Various forms of hydrated and anhydrous calcium sulfate, the key constituent of plaster of paris, are common throughout the deserts of the world.) All this activity can move rocks the way frost does when it shatters, heaves, and sorts the pieces into patterns.

Like ice in the Arctic, though, salt rarely acts alone in the formation of patterned ground features. In a playa such as Badwater Basin, fine silt and clay deposited by infrequent floodwaters also play a central role in the process. As soil dries beneath the salt veneer, it shrinks and cracks—like a mud puddle after rain—creating fissures sometimes two to three feet deep and forming the dominant polygonal pattern. But even as the surface becomes parched and hardened, groundwater—along with its dissolved salt—continues to be drawn upward through the fine-grained soil by capillary action. Upon reaching the open fissures, the water evaporates, salt crystals build up on the fissures' walls, and ramparts rise above the circumscribed polygons, clearly defining each one. In time, accumulating salts widen and accentuate the fissures in much the





JOHN CARBONE/CARBO; BRUCE COLEMAN, INC. INSET: ART WOLFE

Left: Accumulated salts highlight cracks in the floor of Death Valley, California. Similar polygonal shapes can be seen in an aerial view of Alaska's coastal plain (inset).

same manner that slow additions of freezing water gradually increase the width of ice wedges bordering Arctic polygons.

As I hiked up the gently sloping flanks of Badwater Basin's salt pan, I encountered still more patterns in the ground. Low mounds of silty soil pocked the stony desert pavement like so many frost-heaved "boils" in an Arctic coastal plain. Despite Death Valley's extreme dryness, pockets of clay had swelled with moisture during the last rainfall, bulging upward to form these low mounds. Each time this process repeats itself, stones on the surface of the mound move a little, nudged by salt and pulled by gravity toward the edges of the dome, where they eventually come to rest, outlining the circles of bare soil. And like frost boils in the Arctic, many of these circles were marked by rocks thrust upward, broken into layers, and split apart—by salt crystals rather than by freezing water. On steeper inclines, the stones were displaced primarily toward the downslope edge of the mound, and the same process of sorting had led to the formation of small, stone-banked steps or terraces. Some steps even appeared to have crept imperceptibly downward, en masse, just as lobes of soil on Arctic hillsides ooze slowly downhill over the frozen subsoil. This was as clever a trick of nature as I had ever witnessed—a near-perfect duplication of an Arctic landscape pattern in one of the hottest places on earth.

Peter Marchand is a research ecologist at the Catamount Institute, situated on the north slope of Pike's Peak in Woodland Park, Colorado.

UNIVERSE

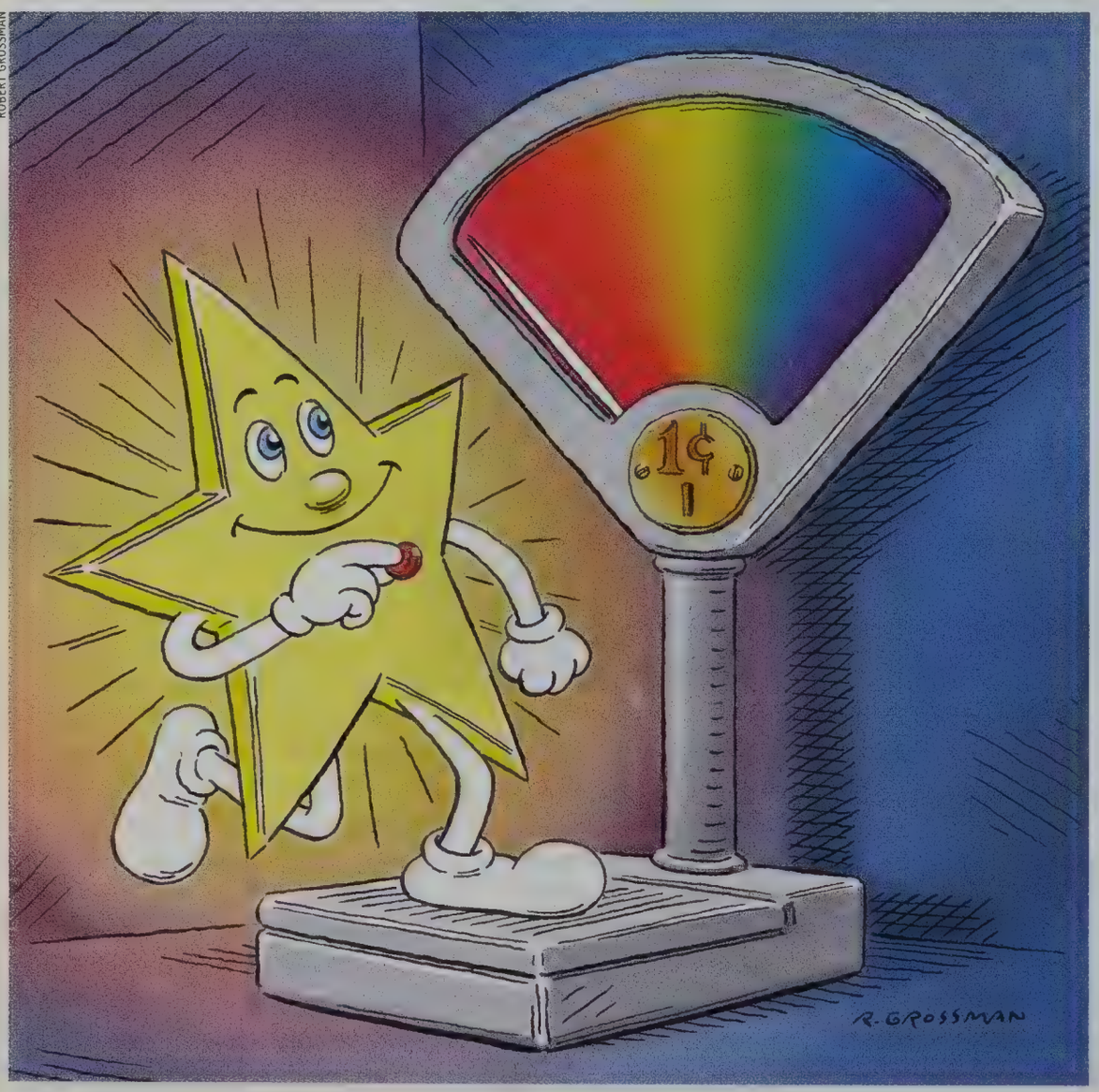
Over the Rainbow

The astrophysicist's pot of gold lies along the entire spectrum.

By Neil deGrasse Tyson

Whenever cartoonists draw biologists, chemists, or engineers, the characters typically wear protective white lab coats with assorted pens and pencils poking out of the breast pockets. Astrophysicists use plenty of pens and pencils, but we never wear lab coats unless we are building something to launch into space. Our primary laboratory is the cosmos, and unless you run into some bad luck and get hit by a meteorite, you are not at risk of getting your clothes sullied or singed. Therein lies the challenge. How do you study something that cannot possibly get your clothes dirty? How do astrophysicists manage to learn anything about either the universe or its contents when all the objects to be studied are light-years away?

Fortunately, the light emanating from a star reveals much more to us than the star's position or brightness. The light also serves as a sensitive probe of the star's atoms, which lead busy lives. Their little electrons continually absorb and emit light. And if the environment is hot enough, collisions between atoms can jar loose some or all of their electrons, scattering light to and fro. Each type of atom leaves its unique fingerprint on the light being studied, implicating the responsible chemical elements or molecules.



ROBERT GROSSMAN

In 1666, Isaac Newton used a prism to disperse white light and produce the now familiar spectrum of seven colors—red, orange, yellow, green, blue, indigo, and violet—that he himself named. (Feel free to call them Roy G. Biv.) Other people had played with prisms before. What Newton did next, however, had no precedent. He passed the emergent spectrum of colors back through another prism and recovered the pure

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white he had started with. This simple exercise demonstrated a remarkable property of light that has no counterpart on the artist's palette—where these same colors of paint, when mixed, leave you with a sludge-colored glob. Further, Newton tried to disperse each of the spectrum's seven colors, but he found them to be pure. The human eye has no capacity to do what prisms do. Another window to the universe lay undiscovered before us.

Were it not for science's ability to analyze light by breaking it up into its component colors, we would know next to nothing about the universe.

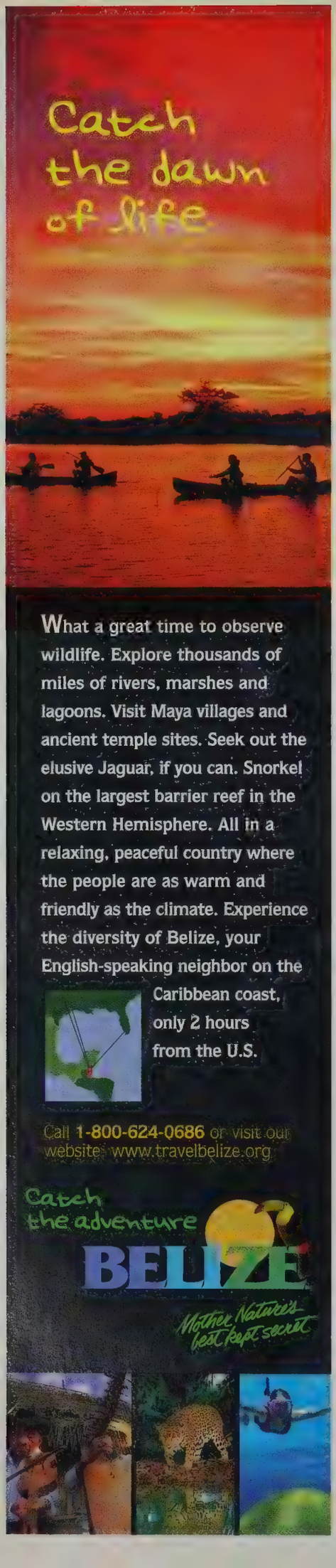
A careful inspection of the Sun's spectrum using precision optics and techniques unavailable in Newton's day reveals not only Roy G. Biv but also narrow segments within the spectrum where color is absent. These "lines" through the light were discovered in 1802 by British physician and chemist William Hyde Wollaston, who naively (though sensibly) suggested that they were naturally occurring boundaries between the colors.

Despite their seven distinct names and the presence of dark lines, spectral colors change gradually from one into the next. Soon the efforts of German physicist and optician Joseph von Fraunhofer produced a more complete discussion and interpretation. Fraunhofer, who devoted his career to the quantitative analysis of spectra and to the construction of optical devices that generate them, is often referred to as the father of modern spectroscopy, but I might make the additional claim that he was the father of astrophysics. Between 1814 and 1817, he discovered that when passed through a prism, the light of certain flames produced patterns of lines that resembled what he had found in the Sun's spectrum, which in turn resembled lines found in the spectra of many stars—including Capella, one of the brightest in the nighttime sky.

By the mid-1800s, German chemists Gustav Kirchhoff and Robert Bunsen (of "Bunsen burner" fame) were making a cottage industry of burning stuff and passing the light through a spectroscope, an optical device with a built-in prism. They mapped the patterns made by known elements and discovered many new ones, including rubidium and cesium. Each element left its own pattern of lines—its own calling card—in the spectrum being studied. So fertile was this enterprise that the second most abundant element in the universe, helium, was discovered in the spectrum of the Sun before it was discovered on Earth. The element's name reflects this history, with its prefix derived from *helios*, "the Sun."

A detailed and accurate explanation of the role played by atoms and their electrons in the formation of spectral lines would not emerge until the era of quantum mechanics, a half century after Kirchhoff and Bunsen. But the conceptual leap had already been made: just as Newton's equations for gravity connected the realm of laboratory physics to the solar system, Fraunhofer connected the realm of laboratory chemistry to the cosmos. He set the stage for others to identify the chemical elements that filled the universe and to determine the conditions of temperature and pressure influencing their spectral patterns.

Among the more boneheaded statements ever made by philosophers, armchair or otherwise, we find the following 1835 proclamation by French logical positivist Auguste Comte: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On the subject of stars, all investigations which are not ultimately reducible to simple visual observations are . . . necessarily denied to us. . . . We shall never be able by any means to study their chemical composition. . . . I regard any notion concerning the true mean temperature of the various stars as forever denied to us.

Quotes like that can make you afraid to say anything in print.

Just seven years later, in 1842, Austrian physicist Christian Doppler proposed what became known as the Doppler effect, which is the change in the frequency of waves emitted by an object in motion. One can think of a moving object, whether a car or a star, as stretching the waves in its "wake" (reducing their frequency) and compressing the waves in front of it (increasing their frequency). The faster the object moves, the more the waves in front of it are compressed and the more those behind it are stretched. This simple relationship between wave speed and wave frequency has profound implications. If you know the natural frequency at which light or sound waves are emitted by an object, but you note a different value when the object is moving, the difference between the two frequencies is a direct indication of the object's speed toward or away from you. In an 1842 paper, Doppler made this prescient statement:

> *It is almost to be accepted with certainty that this [effect] will in the not too distant future offer astronomers a welcome means to determine the movements . . . of such stars which . . . until this moment hardly presented the hope of such measurements and determinations.*

The idea works for sound waves, for light waves, and, in fact, for waves of any origin (although Doppler would surely be surprised to learn that his discovery would one day be used in microwave-based radar "guns" wielded by police officers to extract money from people who drive automobiles above a speed limit set by law). By 1845, Doppler was "conducting" experiments in which musicians played tunes on flatbed railway trains while people with perfect pitch wrote down the changing notes they heard as the trains approached and then receded.

During the late 1800s, the widespread use of spectroscopes, coupled with the relatively new science of photography, enabled the field of astronomy to be reborn as the discipline of astrophysics. One of the preeminent research publications in my field, the *Astrophysical Journal,* was founded in 1895, and until 1962 it bore the subtitle *An International Review of Spectroscopy and Astronomical Physics.* Even today, nearly every paper reporting observations of the universe gives either an analysis of spectra or is heavily influenced by spectroscopic data obtained by others. Since much more light is needed to generate the spectrum of an object than to take its snapshot, the biggest telescopes in the world, such as the twin 10-meter Keck telescopes in Hawaii, each with nearly twenty times the light-gathering power of the Hubble Space Telescope, are tasked primarily with obtaining spectra.

Were it not for science's ability to analyze light by breaking it up into its component colors, we would know next to nothing about the universe. Astrophysics educators thus face a pedagogical challenge of the highest rank. We deduce nearly all our scientific information about the structure, formation, and evolution of objects in the universe by studying spectra, but the analysis of a spectrum is removed by several levels of abstraction from the thing being studied. In some cases, analogies and metaphors can help link complex, somewhat abstract ideas to simpler, more tangible ones. The biologist might describe the shape of the DNA molecule as two coils connected

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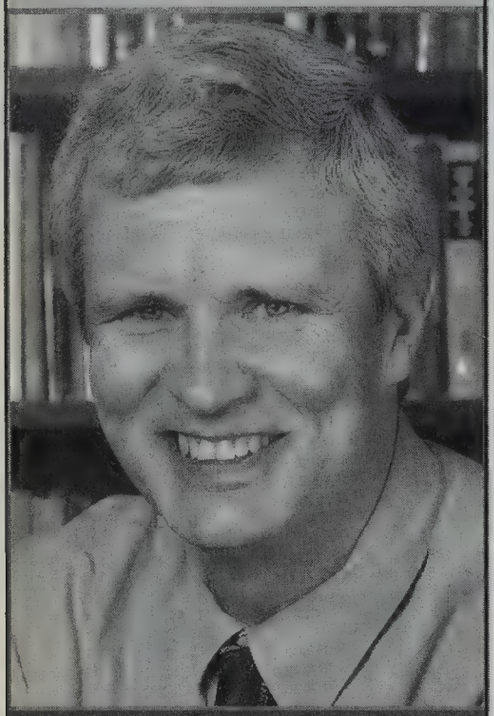
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to each other the way rungs on a ladder connect the ladder's sides. I can picture a coil. I can picture two coils. I can picture rungs on a ladder. I can therefore picture the molecule's shape. Each part of the description sits only one level of abstraction removed from the molecule itself. And they come together nicely to make a vivid image in the mind. However easy or hard the science is, one can now at least talk about this molecule.

But to explain to an audience how we know the speed of a receding star requires five nested levels of abstraction:

Level 0: Star
Level 1: Picture of a star
Level 2: Light from the picture of a star
Level 3: Spectrum from the light from the picture of a star
Level 4: Patterns of lines in the spectrum from the light from the picture of a star
Level 5: Shifts in the patterns of lines in the spectrum from the light from the picture of a star

Going from Level 0 to Level 1 is a trivial step we all take every time we get pictures back from the photo processor. But by the time a scientist's explanation reaches Level 5, the audience is either befuddled or fast asleep. The public hardly ever hears about the role of spectra in cosmic discovery because the concept is just too far removed from the objects themselves to be explained efficiently. When creating exhibits for natural history museums, or for any museum where real things matter, what designers typically seek are objects and artifacts suitable for display—rocks, bones, tools, fossils, memorabilia, and so forth. All these are Level 0 specimens, requiring little or no cognitive investment from viewers before they can process the explanation of what the item is. But astrophysicists have a problem: they cannot place cosmic specimens on display because most of them would vaporize the museum.

Photographs can show us that dying high-mass stars explode. But X-ray and visible-light spectra show us that heavy elements spew from these stars, enriching the galaxy.

Most astrophysics exhibits are therefore conceived in Level 1, leading principally to displays of pictures—some quite gorgeous. The most famous telescope in modern times is, of course, the Hubble, known to the public primarily through the beautiful, full-color, high-resolution images it has produced of objects in the universe. The problem here is that after viewing such exhibits, you wax poetic about the beauty of the universe yet are no closer than before to understanding how it all works. To really know the universe requires forays into Levels 3, 4, and 5. While much good science has come from the Hubble telescope (including the most reliable measure to date for the expansion rate of the universe), you would never know from media accounts that the foundation of our cosmic knowledge continues to flow primarily from the analysis of spectra and not from looking at pretty pictures.

I want people to wax poetic not only after exposure to Levels 0 and 1 but up to and including exposure to Level 5, which admittedly requires a greater intellectual investment on the part of the student and (perhaps especially) on the part of the educator.

For example:

It's one thing to see a beautiful color picture, taken in visible light, of a neb-

ula in our own Milky Way Galaxy. But it's another thing to know from its radio-wave spectrum that the nebula also harbors newly formed stars of very high mass within its cloud layers. This gas cloud is a stellar nursery, regenerating the light of the universe.

It's one thing to know that high-mass stars explode every now and again. Photographs can show us this. But the X-ray and visible-light spectra of these dying stars reveal a cache of heavy elements that enrich the galaxy and can be directly linked to the constituent elements of life on Earth. Not only do we live among the stars, the stars live within us.

It's one thing to look at a poster of a pretty spiral galaxy far beyond our own. But it's another thing to know from Doppler shifts in its spectral features that this particular galaxy is rotating at 200 kilometers per second—from which, using Newton's laws of gravity, we infer the presence in it of 100 billion stars. And by the way, the Doppler shifting also tells us that the galaxy is receding at one-tenth the speed of light.

It's one thing to look at nearby stars that resemble the Sun in luminosity and temperature. But it's another thing to use hypersensitive Doppler measurements of a star's motion to infer the existence of planets in orbit around them. At press time, our catalog of extrasolar planets nears 100 entries.

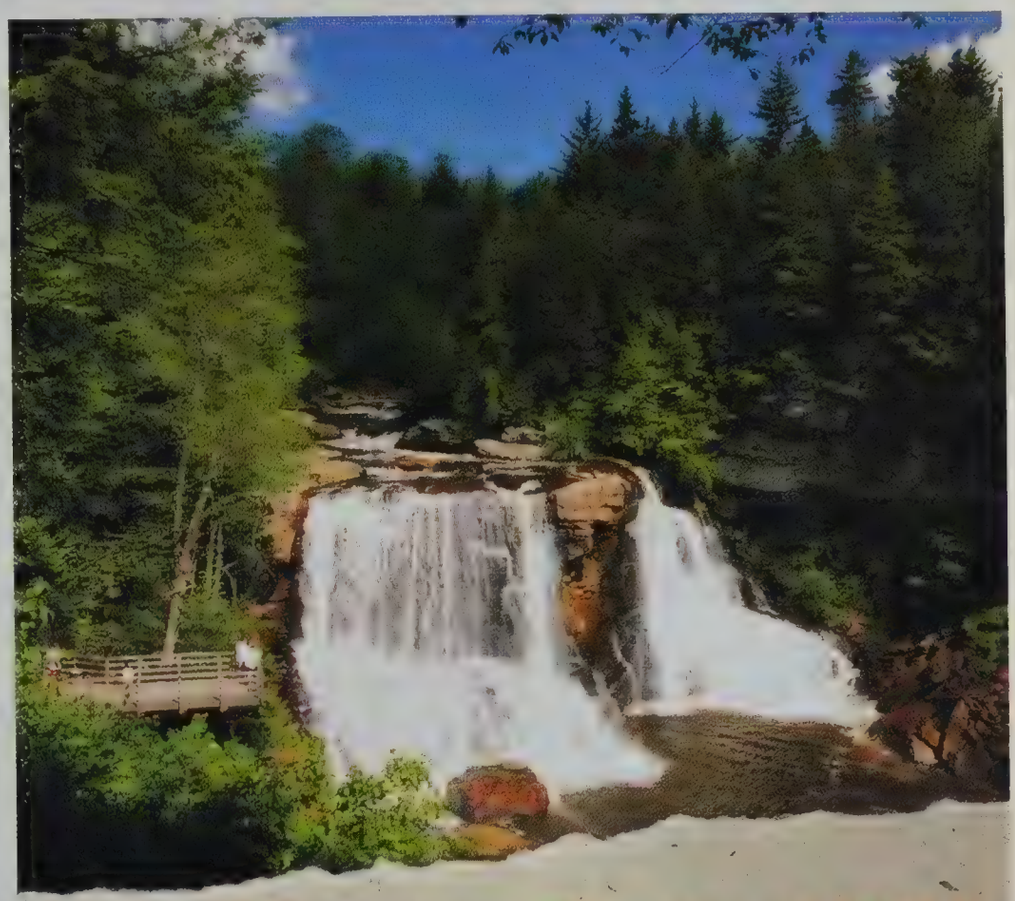
It's one thing to observe the light from a quasar at the edge of the universe. But it's another thing entirely to analyze the quasar's spectrum and deduce from that analysis the structure of the invisible universe—the gas clouds and other obstructions that lie along the quasar's path and take a bite out of its spectrum.

Fortunately for the magnetohydrodynamicists among us, atomic structure changes slightly under the influence of a magnetic field. Where can this change be seen? In the slightly altered spectral patterns caused by these magnetically afflicted atoms.

And armed with Einstein's relativistic version of the Doppler formula, we deduce the expansion rate of the entire universe from the spectra of countless galaxies, near and far, and thus infer the age and fate of the cosmos.

One could make a compelling argument that astrophysicists know more about the universe than marine biologists know about the ocean floor or geologists know about the center of Earth. Far from leading an existence as powerless stargazers, we are armed to the teeth with the tools and techniques of spectroscopy, enabling us *Homo sapiens* to stay firmly planted on Earth yet finally to touch the stars—without burning our fingers—and claim to know them as never before.

Astrophysicist Neil deGrasse Tyson is the Frederick P. Rose Director of New York City's Hayden Planetarium and a visiting research scientist at Princeton University.



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Freshwater Riches of the Amazon

To find the reasons for a river's abundance, a scientist goes fishing in deep time.

Story by John Lundberg ~ Painting by Ray Troll

Home to more than two thousand freshwater fish species, the Amazon, ichthyologically speaking, is the hottest big river on the planet. Some of its inhabitants are familiar: cardinal tetras, discus, angel cichlids, and armored "pleco" catfish inhabit home aquariums; trophy-sized peacock bass and goliath catfishes beckon sporting anglers; giant-sized tambaqui and pirarucú are prime food fishes for residents of the region; and piranhas, electric eels, and river stingrays contribute to tales of tropical danger. But any notion that science has achieved a complete inventory of the Amazon's, or the world's, fishes is utterly dispelled by ongoing discoveries. Each year since 1960, more than 35 tropical American species of fishes, including catfishes, characins, electric fishes, killifishes, and cichlids, have been newly described and named. During the past decade the pace has quickened, with more than 50 fishes coming to scientific light annually. By contrast, the Congo River of Africa has about 700 fish species in total, and the well-studied Mississippi-Missouri of North America, a relatively scant 375.

I had surveyed the fishes of the Orinoco River system of Venezuela and Colombia for many years before my first visit to the Amazon in 1990. For an

ABOUT THE ARTIST

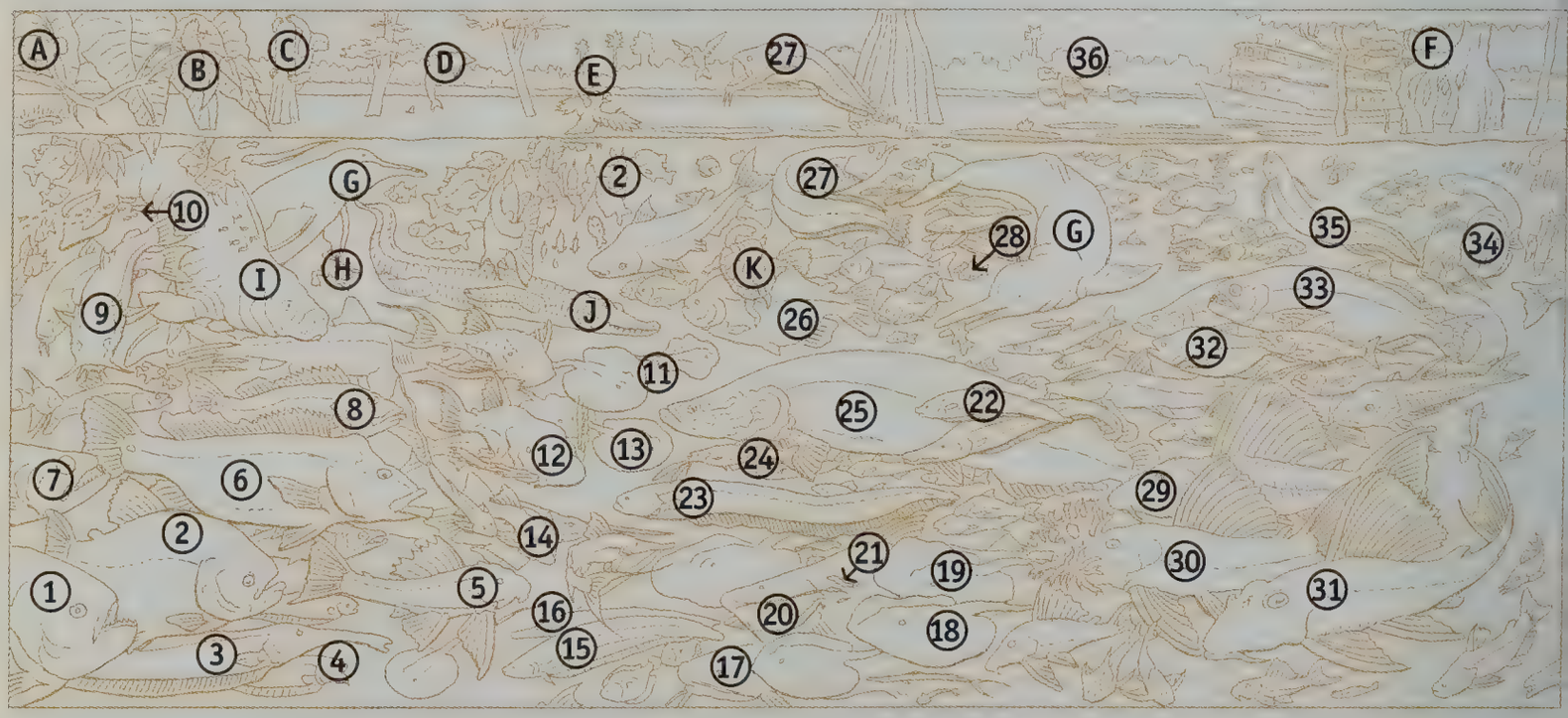
In 1997, artist and fish aficionado Ray Troll traveled 1,000 miles of the Amazon. The river's diversity inspired a seven-by-fifteen-foot painting of 120 species.

ichthyologist, the Amazon represents a pinnacle of diversity, but I also wanted to investigate the history and origins of the river's many fish species. Biogeography is the science that seeks to document and explain patterns of diversity and regional differences in species abundance, so I delved into the ancient geography of South America to find out just why the Amazon has so many fishes.

Two broad, global patterns of biogeography help explain Amazon fish diversity, but they don't tell the whole story. Size matters, and the Amazon River basin is a large, watery place, covering more than 2.5 million square miles, or 30 percent of the South American continent. In terms of water volume, no other river on earth comes close to it. In the rainy season, the Amazon discharges 3–6 million cubic feet of water per second into the Atlantic and accounts for 20 percent of the worldwide flow

Size is at best a partial explanation for the Amazon's bounty.

of freshwater into the oceans. So we might expect the vast basin, or watershed—consisting of the main stem of the Amazon and its thousands of tribu-



FISH . . .

1. Black piranha, *Serrasalmus rhombeus*
2. Red-bellied piranha, *Pygocentrus nattereri*
3. Thin-nosed tube-snout knifefish, *Sternarchorhynchus oxyrhynchus*
4. *Sternarchogiton* sp.
5. Dark-spotted armored catfish, *Pterygoplichthys* sp.
6. Speckled peacock bass, *Cichla temensis*
7. Freshwater dogfish, *Rhaphiodon vulpinus*
8. Peacock bass, *Cichla ocellaris*
9. Pirarara (red-tailed) catfish, *Phractocephalus hemioliopterus*
10. Cardinal tetra, *Paracheirodon axelrodi*
11. Motoro, *Potamotrygon* sp.
12. Royal pleco, *Panaque nigrolineatus*
13. Reticulated stingray, *Potamotrygon reticulatus*
14. Common pleco, *Hypostomus* sp.
15. Duke's channel knifefish, *Magosternarchus duccis*
16. Tamandua tube-snout knifefish, *Orthosternarchus tamandua*
17. Black piraiba catfish, *Brachyplatystoma* sp.
18. Tiger stingray, *Potamotrygon* sp.
19. Faulkner's stingray, *Potamotrygon faulkneri*
20. Piraiba catfish, *Brachyplatystoma filamentosum*
21. Candirú catfish, *Vandellia plazaii*
22. Tooth-lip knifefish, *Oedemognathus exodon*
23. Electric eel, *Electrophorus electricus*

taries—to contain many fish species. Yet the Orinoco, with a watershed area of less than half a million square miles, boasts at least 1,000 species, and even smaller rivers of the Guianas teem with hundreds of species. Size, then, is at best a partial explanation for the fish-rich Amazon.

A second general pattern, which holds true for tropical America's birds, reptiles, amphibians, mammals, insects, marine fishes, invertebrates, and plants—that is, most organisms—is known as the latitudinal diversity gradient. Long recognized but never fully explained, this is the trend for life to be more diverse in tropical, low-latitude regions. It is a fact of geography that near the equator, the earth receives more energy from the sun. Temperature and day length are more seasonally stable (although in many cases rainfall is not). Under these conditions, vegetation abounds and, in turn, can support many animals of many species, including some that have extremely specialized lifestyles and exist only in small populations. The Amazon is full of gastronomic specialists. *Hypophthalmus,* for example, eats tiny zooplankton; other fish eat snails (*Megalodoras uranoscopus*), the scales of other fish (*Catoprion*), the tails of other fish (*Magosternarchus*), chunks of flesh and fins (piranhas), fruits and seeds (tambaqui), wood (*Panaque*), or blood and gills (candirú catfish). (One species of candirú catfish, which is attracted to the flow of water from the gills of its prey, has become notorious for its unfortunate tendency to mistake a stream of urine for gill flow and to enter human urethras.)

While river systems both large and small in the northeastern two-thirds of the continent appear to exemplify the tendency of low latitudes to be species rich, other South American rivers do not. Fish diversity falls off precipitously in the watersheds north and west of the Andes. These rivers and tributaries are flanked by some of the richest land and marine communities, but by South American standards, they have relatively few freshwater fishes. For example, the Magdalena River and Lake Maracaibo in the northwest each host only about 150 species.

While heat, sunlight, and ample food can help maintain tropical diversity, they do not explain how great diversity arose in the first place. The bounty of the Amazon can be accounted for only if we consider time as well as space. Biogeographical pat-

Adapted for life in turbid waters, the Amazon river dolphin has extremely small eyes. It uses its finely tuned echolocation skills to detect prey.

24. *Hypophthalmus fimbriatus*
25. Pirarucú, *Arapaima gigas*
26. Tambaqui, *Colossoma macroponum*
27. Arowana, *Osteoglossum bicirrhosum*
28. Harald Schultz's cory, *Corydoras haraldschultzi*
29. *Hypostomus* sp.
30. Polka-dot bristlenose catfish, *Ancistrus lineolatus*
31. Goldy pleco, *Scobiancistrus aureatus*
32. Elongate piranha, *Serrasalmus elongatus*
33. Pirandirá vampirefish, *Hydrolycus scomberoides*
34. Heckel discus, *Symphysodon discus*
35. American lungfish, *Lepidosiren paradoxa*
36. Hatchetfish, *Thoracocharax stellatus*

. . . AND FRIENDS

A. Squirrel monkey, *Saimiri sciureus*
B. Green kingfisher, *Chloroceryle americana*
C. Three-toed sloth, *Bradypus tridactylus*
D. Tucuxi dolphin, *Sotalia fluviatilis*
E. Hoatzin, *Opisthocomus hoazin*
F. Jaguar, *Panthera onca*
G. Amazon river dolphin, *Inia geoffrensis*
H. Surinam toad, *Pipa pipa*
I. Amazonian manatee, *Trichechus inunguis*
J. Spectacled caiman, *Caiman crocodilus*
K. Yellow-spotted Amazon turtle, *Podocnemis unifilis*

Wired for life in the deep: *Orthosternarchus,* a nearly blind electric fish, and *Magosternarchus,* an electric tail-eating species (long blue-gray and red fishes at lower right). A nonelectric, armored catfish swims above a ray (left).

terns, particularly those of fishes, are rooted deep in the past. As denizens of rivers, streams, and lakes, the largest groups of endemic, or native, freshwater fishes in South America are relatively confined. Unlike many other creatures, they can neither move through coastal saltwater nor traverse land barriers. Where they are and how they move about depend on changes of continental proportions that have taken place at a geologically slow pace.

One controversial theory that seeks to explain tropical America's biodiversity holds that climatic shifts starting about 2 million years ago and continuing through the Pleistocene Epoch, or until about ten thousand years ago, caused the repeated fragmentation and merging of tropical rainforests. Such shifts provided multiple opportunities for birds, butterflies, and plants to diverge and eventually be-

Dark New World

The Amazon and its tributaries are not only vast but also fast moving, deep, and dark. In the clearer tributaries an observer may peer down to a depth of several yards, but in most of this silt-laden river system, light does not penetrate even three feet. One of the main challenges faced by ichthyologists hoping to discover and document the fish species in very big South American rivers is to devise ways to survey less accessible parts of the channels. My colleagues and I found that from large boats or even motorized canoes, we could trawl depths of a few to more than 150 feet by casting a weighted net with a wide mouth and very fine mesh. In the process, we lost plenty of equipment as our gear snagged on submerged trees and rocks in water that was moving six or more feet per second.

So far on our Amazon collecting trips, we have netted some 240 species of fish, some of them with surpassingly strange lifestyles. Especially well adapted to low or nonexistent light levels are several new species of electric fishes and catfishes. Many, such as the electric fish *Orthosternarchus* and the catfish *Bathycetopsis,* are blind or have only tiny vestigial eyes; some lack pigment. One transparent catfish, *Micromyzon,* has thick bones and armor plating but is among the tiniest of freshwater fish: an adult specimen carrying eggs measured just one-third of an inch long. Electric fishes of deep waters are able to navigate and locate prey using electric impulses. Each species has its own distinct patterns of electric discharges that it uses to communicate, much like birds use song. One electric fish bears a fleshy protrusion above its chin; we can only guess what that feature might be used for.

Some catfishes provide abundant food for the people living in the Amazon River basin and are often caught as adults in shallow water near river banks. But they appear to spend their juvenile stage floating and feeding near the surface of the river's central channels. Understanding such lifestyles is important for managing the harvest of food fish in the Amazon.

Two of the strangest creatures in this new realm are a pair of related electric fish species that we named *Magosternarchus raptor* and *M. duccis.* About ten inches long, these fishes make a living by feeding on the tails of other species of electric fish. We found this out when their stomachs proved to contain nothing but fish tails. Their victims can conveniently regenerate the nibbled appendage, renewing their own posteriors and the food source of the tail eaters. (We suspect that *Magosternarchus* may also dine on the tails of its own kind.) While we expect the Amazon and other big tropical rivers around the world to reveal more secrets in the future, some spots in these rivers run forbiddingly deep—up to 300 feet in the Amazon near Manaus, Brazil—and this may be deep enough to preserve some riverine mysteries.—*J. L.*

MAPS BY JOYCE PENDOLA

Left: Millions of years ago, the major river systems of South America flowed north–south.

As the Andes rose, Lake Maracaibo and the Magdalena River were isolated in the northwest, and the Orinoco and Amazon Rivers took 90° turns and began to flow into the Atlantic, left and detail above.

come new species. But in the case of fishes, a time frame of 2 million years is just yesterday. Long before the Pleistocene, the Amazon teemed with species that are closely related to fishes alive today in the river. We need, then, to consider phenomena much older than 2 million years as we search for clues to the diversification and biogeography of Amazon fishes.

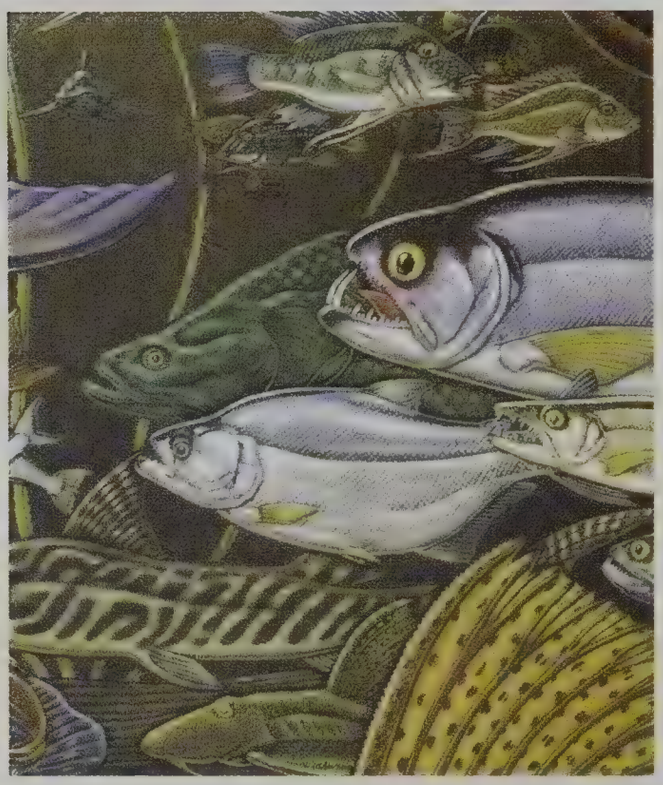
As early as the middle Miocene, about 15 million years ago, the tropical American fish fauna was

For fishes, 2 million years ago is just yesterday.

essentially like today's. It included many living groups: stingrays, lungfish, pirarucú, piranha, goliath catfishes, some electric fishes, and cichlids. A primatologist friend and colleague once showed me a fossil of a 13-million-year-old fish he had excavated in Colombia. He had no idea what kind of fish he had found and was struck by its particularly large teeth. He was surprised when I was able to identify the fossil; the specimen looked just like a living fish I knew well, the tambaqui. Although no longer found in the rivers of central Colombia, the tambaqui, which feeds on seeds and fruits that fall from trees in the seasonally flooded forests, thrives today in the Amazon. Similarities between ancient and modern fishes crop up even further back in time. One well-preserved fossil fish about 59 million years old looks like, and is indeed related to, the *Corydoras* catfish popular today in the aquarium trade. And some fossil catfishes, lungfishes, and characins date back to the Late Cretaceous, 70 million years ago.

Today, 93 percent of South American freshwater drains into the Atlantic, but this was not always the case. The stage on which the present pattern of rivers took shape was the continent itself. The players, South America's major physical features, included two huge slabs of stable continental crust, known as the Guyana and Brazilian Shields; the dynamic Andes mountain range; and the vast lowlands that lay between the shields and the mountains. About 90 million years ago, South America and Africa (both of which had earlier been part of the southern supercontinent of Gondwana) separated from each other. As South America, which comprised a continental plate, moved west, it crashed against an oceanic plate moving east. The collision caused the land along the west coast of South America to rise up, and the first stage of Andean mountain building began. During their long history, the Andes underwent several phases of uplift and subsidence. As the mountains grew, adjacent land to the east and north buckled, forming a

troughlike basin running north and south. At times the basin was filled with sediment; at wetter intervals it contained large lakes, was periodically inundated by shallow ocean waters, and channeled major rivers in a north–south direction. Taken together, the formation of Andean and other land barriers, the shifting courses of rivers, and sporadic incursions of ocean waters would have produced many opportunities for fish species to evolve as some populations were isolated from others and began to adapt to new conditions.



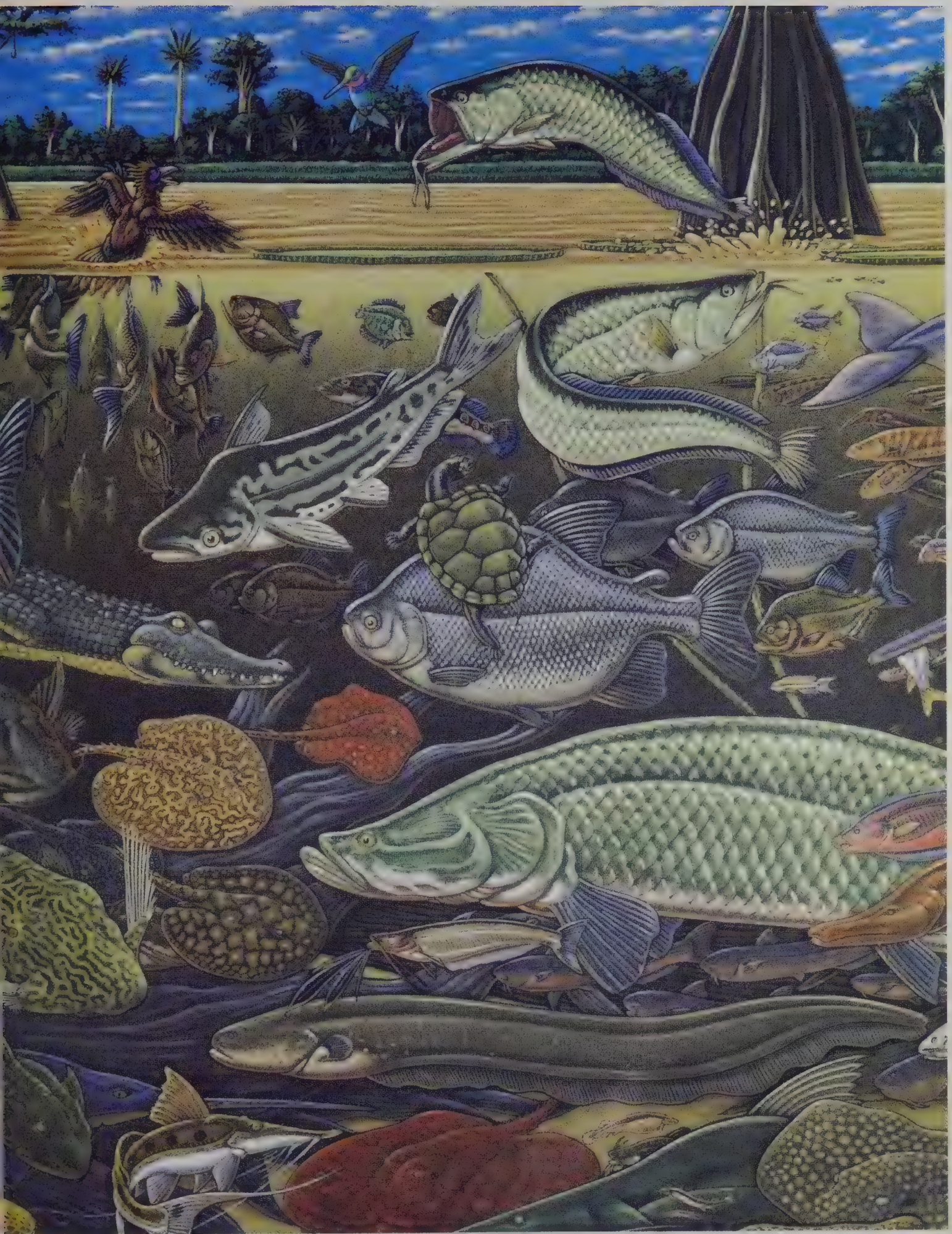
A toothy pirandirá vampirefish and smaller elongate piranha, right. Opposite page: Representing the world's biggest freshwater food fish, a pirarucú swims just below a tambaqui, as arowanas leap at the water's surface.

Long before the end of the Miocene, a great river, consisting of what are today the western Amazon and the Orinoco, flowed north through the lowland basin and into the Caribbean. About 10 million years ago, the rise of the eastern Andes created the Magdalena River basin in Colombia. Uplift continued until, by 8 million years ago, the mouth of the north-flowing Amazon-Orinoco was dammed. The river could no longer reach the Caribbean Sea. This major event in the geographical history of South America split the Orinoco and Amazon and reoriented their course from north–south to west–east. The Amazon began to flow into the Atlantic, as it does today. Over time, new rivers appeared in the north, and 3.5 million years ago the elevation of the Isthmus of Panama formed a bridge between the American continents.

As rivers appeared, disappeared, and changed course, their communities of fishes went along for the ride. The ranges of various species expanded, merged, or were disrupted. The geological upheavals that divided rivers and river basins provided opportunities for speciation when fish populations were isolated. The results are the species that today are found only in those systems. However, fossils from the regions now occupied by the Magdalena River and Lake Maracaibo show they once contained fishes no longer found there but that still inhabit the Amazon. These include lungfish, *Arapaima*, tambaqui, piranha, *Hydrolycus*, and goliath and pirarara catfishes. Although the fossil record documents such localized extinctions of living fish groups, we have no evidence of widespread extinctions and only two or three cases in the past 65 million years in which an Amazon fish species was completely extinguished.

The biodiversity equation is balanced by speciation on one side and extinction on the other. Low extinction rates are part of the formula for fish-species richness in the Amazon basin and eastern South America. But in other regions of the world, freshwater fishes also provide textbook examples of rapid species formation. Chief among these examples are the African cichlids, which, in a geologically brief period (perhaps less than 100,000 years), evolved into hundreds of species that now live in the same body of water. In contrast, we have no evidence for any unusually high rates of speciation among fishes in South America. Given enough time and low extinction rates, a normal tempo of speciation gave rise to the Amazon's array.

Since the day I recognized my colleague's fossil as almost identical to a modern fish, I have discovered several other examples of this phenomenon, and I am still struck by the great antiquity of many of the living tropical American fish species. By comparison, the history of other groups, such as mammals, has been fast paced and marked by high turnover. Tropical American mammal species have immigrated, emigrated, evolved, and gone extinct with a rapidity that makes Amazon fishes look frozen in time. Fish like the tambaqui—whose fossil and modern jaws and teeth reveal unmistakable similarities—have, except in the restless edges of their ranges, changed little over the past 15 million years. As continents separated and connected, as the Andes grew and rivers took right-angle turns, the tambaqui persisted in its specialized diet of fruits and seeds. This fish and many modern-day finned icons of the Amazon recount a long and enlightening chapter of the story of life on earth. □



Out of Thin Air

A very special group of microbes tap into the atmosphere's huge storehouse of nitrogen and make it available to the rest of us.

By David W. Wolfe

Lightning and some bacteria that live in the roots of certain plants, such as lupines, opposite page, share the rare ability to "fix" nitrogen gas, turning it into a form that plants and animals can use.

Take a deep breath. Most of what is filling your lungs is not oxygen but nitrogen, in the form of N_2 gas. Every cubic yard of the air around us, in fact, is about 80 percent N_2. On the face of it, this abundance would appear to be an unqualified blessing, for nitrogen is an essential ingredient of life—a key component of amino and nucleic acids, the basic building blocks of proteins and our genes. There is a catch, however. This immense supply might as well be on Jupiter or Mars as far as most living things are concerned. No animal, plant, fungus, or protist has mastered the chemical art of converting the abundant gaseous form of nitrogen into a biologically useful one. In fact, if N_2 were the only nitrogen available, most species would quickly go extinct—like sailors dying of thirst while adrift on a life raft at sea. Fortunately, within the dark and hidden realm that is the ground beneath our feet—a realm generally ignored by us oversized, sunlight- and oxygen-dependent "surface chauvinists"—live a handful of bacterial species that can metabolize N_2 and thereby bring this nitrogen into the food chain.

Earth's first microbes, which emerged about 3.5 billion years ago, had no such ability. N_2 became available to them only when it was transformed into nitrate (NO_3, nitrogen combined with oxygen) during lightning strikes and meteor impacts. At that time, the energy and heat generated by these random events were the only forces in nature capable of breaking the powerful chemical bond that holds the two atoms of N_2 together. This sprinkling of nitrate from the heavens had some inherent

Adapted from *Tales From the Underground: A Natural History of Subterranean Life,* by David W. Wolfe.
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limitations with regard to supporting life on earth, however. For one thing, nitrate is easily washed away by rain and often winds up in groundwater, rivers, and ultimately the oceans before any terrestrial organisms can make use of it. For another, once photosynthesis evolved (perhaps 3 billion years ago), the number of living things on earth expanded rapidly, creating a demand for usable nitrogen that exceeded this meager supply.

Enter a unique group of bacteria that "invented" a way to convert, or fix, N_2 gas into ammonia (NH_3, another usable form of nitrogen, this time in combination with hydrogen) without the intense heat and pandemonium that come with lightning bolts and meteor bombardment. When these bacteria die and decompose, or are consumed by other organisms, the nitrogen they managed to incorporate into their cells becomes available to the rest of us. Essentially all the nitrogen contained within the proteins and genes of plants, animals, and humans has, at one time or another, been funneled through these nitrogen-fixing microbes.

A single pinch of garden soil may contain 10,000 bacterial species, but probably no more than

Alders host nitrogen-fixing bacteria in the genus *Frankia*, which nourish the trees and help maintain healthy nitrogen levels in the soil.

100 to 200 species of free-living nitrogen fixers exist worldwide. Many of these are members of an ancient group of self-sufficient organisms known as cyanobacteria, which can fix both carbon (through photosynthesis) and nitrogen. Cyanobacteria are vitally important as "primary producers" at the base of the food chain in the oceans. On land, the most common and important nitrogen-fixing bacteria are those that live symbiotically within the roots of plants, providing their hosts with nitrogen and receiving in return the products of photosynthesis (carbon-laden, energy-rich sugars).

ART WOLFE

With 99 percent of soil organisms not yet named or studied, we still have much to learn about subterranean symbioses and the nitrogen cycle. Scientists frequently turn up new nitrogen-fixing microbes, some of which form partnerships with animals rather than plants. For example, bacteria living in the intestinal glands of a wood-boring mollusk known as the shipworm provide the animal with as much as one-third of its nitrogen. And recently, researchers identified a nitrogen-fixing spirochete bacterium that lives in the gut of termites.

All of the world's nitrogen fixers, whether free-living or symbiotic, rely on the same enzyme—nitrogenase—to do the job. Nitrogenase is a giant among enzymes, both in the literal sense (it is a huge and complex molecule) and in its significance for earth's biochemistry. Those of us who tend to fret about nature's fragile balance find it a bit disconcerting to learn that our planet's entire supply of nitrogenase could fit into a single large bucket. Lose this, and life as we know it would come to a screeching halt.

SEM BY JEREMY BURGESS/S.P.L.; PHOTO RESEARCHERS, INC.

Below: A nodule on the root of a pea plant. Bottom: Nodules clustered on the root of a soybean plant. Symbiotic bacteria housed within the nodules provide the plant with usable nitrogen.

The planet's entire supply of nitrogenase—the enzyme on which all nitrogen fixers depend—could fit into a single large bucket.

Modern molecular techniques have identified more than twenty bacterial genes involved in the manufacture and control of nitrogenase, while X-ray crystallography and other techniques have revealed the enzyme's structure: long, twisted chains of atoms, arranged like spaghetti, or a ball of yarn after a cat has been playing with it. Nitrogenase actually consists of two huge proteins that physically separate and reunite eight times in the course of 1.2 seconds as they work to break the bond between the two nitrogen atoms and convert one molecule of N_2 into two molecules of ammonia. Most chemical reactions occur in millionths of a second; a duration of 1.2 seconds is almost

DAN GURAVICH; PHOTO RESEARCHERS, INC.

unheard-of, and it reflects how difficult nitrogen fixation is and how much energy must be expended to accomplish it. Nitrogen-fixing bacteria that can team up with plants or animals have the advantage of using the energy-rich sugars they receive from their hosts to help defray some of these manufacturing costs.

Only a century ago did biologists discover that some plant species allow nitrogen-fixing bacteria to invade their root systems and that the nitrogen supplied by this symbiosis eventually becomes available to entire plant and animal communities. Two obscure German agricultural scientists, Hermann Hellriegel and Hermann Wilfarth, uncovered the phenomenon in the mid-1880s while conducting a series of routine greenhouse experiments to determine the fertilizer needs of various crops. Their curiosity got the better of them when they noticed that, unlike other crops, plants in the legume family—

RICHARD HAMILTON SMITH

Legumes—including soybeans, below, acacias, lupines, and clovers—open up their roots to nitrogen-fixing bacteria in the genus *Rhizobium*.

German chemist Fritz Haber was the first human to fix nitrogen synthetically without blowing up his laboratory in the process.

beans, peas, alfalfa, lupines, vetch—thrived even in nitrogen-deficient soils.

In a definitive experiment, Hellriegel and Wilfarth showed that peas grown in steam-sterilized soil developed yellow leaves and other symptoms of nitrogen deficiency. This proved that something *living* in the soil was providing the legumes with nitrogen and suggested that some type of symbiosis might be involved. A few years later, in 1888, a young Dutch scientist named Martinus Biejerinck isolated bacteria belonging to the genus *Rhizobium* growing within the small nodules visible on the roots of legume plants.

We now know a great deal about how nitrogen fixing in legumes works. Essential to the process is the ability to screen the tens of thousands of bacteria in the soil, picking out the few "good guys"—*Rhizobium* bacteria—that are allowed to penetrate the roots. In the course of many millions of years, the host plants have evolved defense mechanisms against bacterial infection. Overriding these defenses requires some complex underground chemical communication, orchestrated by genes in both the plants and the nitrogen-fixing bacteria.

The plant takes the first step in establishing friendly relations. When it reaches a particular stage of development and when environmental cues are just right, certain of the plant's genes turn on, inducing the roots to produce and exude compounds called flavonoids. The flavonoids attract rhizobial bacteria and also activate several of their genes.

Once this chemical handshake has taken place, the rhizobia begin to produce complex sugars and enzymes that cause the tiny root hairs of the plant to curl and allow the bacteria to enter. The rhizobia then wend their way into the root until they encounter special host cells, in which they set up shop. From this point on, the bacteria and the plant—members of two separate kingdoms—share the know-how and labor needed to construct what is essentially a new organ: a fully operational nitrogen-fixing root nodule. The plant does most of the work, while the rhizobia direct matters by sending out a sequence of chemical signals that turn various plant genes on and off. One important step is the creation of a semipermeable membrane around the

Fritz Haber's Reversal of Fortune

During World War I, Fritz Haber, "the man who fixed nitrogen," was asked to spearhead the German effort to develop chemical weapons. Haber agreed, rationalizing that the threat of such weapons would shorten the war and result in less suffering overall. Other scientists were appalled. When Haber was awarded the Nobel Prize in Chemistry in 1918 for his work on nitrogen fixation, Frenchmen who had been offered awards that year declined them in protest, calling him "morally unfit for the honor."

Shunned and misunderstood outside Germany, Haber maintained an active laboratory in his beloved homeland until the Nazis took power in the 1930s. Max Planck, a high-ranking German physicist, reputedly tried to defend Haber and other Jewish scientists during a conversation with Hitler. The Führer is said to have replied, "If the dismissal of Jewish scientists means the annihilation of contemporary German science, then we shall do without science for a few years."

Haber fled Germany in 1933. Because of his World War I activities, however, he was unwelcome in much of Europe. Within one year of exile, on January 29, 1934, he died in his sleep of a heart attack in Basel, Switzerland.—*D. W.*

developing nodule; this membrane will allow the selective exchange of ammonia, sugars, and other nutrients between bacteria and plant. Soon the bacteria get down to the business of fixing nitrogen that enters the nodule from air spaces in the surrounding soil.

Each type of nitrogen-fixing bacterium must also devise a mechanism for shielding nitrogenase from oxygen, because exposure to oxygen destroys this all-important enzyme. Rhizobia on a pea plant, for example, signal the plant to synthesize leghemoglobin, a large molecule that has an even higher affinity for oxygen than does the hemoglobin of our blood. The leghemoglobin binds to any stray oxygen entering the nodule from air spaces and prevents it from reacting with the nitrogenase. (Like hemoglobin, leghemoglobin contains iron and turns deep red when oxygenated. In the field, scientists check for active nodules by cutting into one or two and looking for the characteristic pinkish to blood-red color of the fluids inside.)

Thousands of years ago—long before scientists understood all these details—the value of rotating legumes with other crops was recognized. The Roman poet Virgil (70–19 B.C.) recommended rotation with legumes in part 1 of *The Georgics*, his ode to workers of the land:

> Sow in the golden grain where previously
> You raised a crop of beans that gaily shook
> Within their pods, or a tiny brood of vetch,
> Or the slender stems and rustling undergrowth
> Of bitter lupine. . . .
> . . . . . .
> Thus will the land find rest in its change of crop,
> And earth left unploughed show you gratitude.

Legumes continue to be of tremendous importance in agriculture, both as high-protein foods for animals and people and as "green manure" for the soil. Today, seeds of legumes sold to farmers are routinely inoculated with strains of *Rhizobium* selected for maximum nitrogen-fixing ability. Leguminous trees—including mesquite in the Mojave Desert, acacias in semideserts and savannas, and several tropical hardwoods—play an important role in maintaining nitrogen levels in the soils of some natural ecosystems. In some forests of Scandinavia, the Pacific Northwest, and other temperate regions, nitrogen-fixing bacteria in the genus *Frankia* dominate, providing nitrogen through their association with alder, bayberry, and other tree and shrub species.

A modern nitrogen-fertilizer factory in Louisiana, bottom, uses a process invented nearly a century ago by Fritz Haber, below.

SCIENCE PHOTO LIBRARY; PHOTO RESEARCHERS, INC.

BRIAN MILLER; EARTH SCENES

Just as nitrogen fixation is energetically costly for the bacteria, it is also expensive for the plant. Symbiotic nitrogen-fixing bacteria often burn up about 20 percent of the carbohydrates produced by their hosts. Preliminary results obtained by my research group at Cornell University and by others suggest some intriguing possibilities for the future. As rising levels of atmospheric carbon dioxide (associated with the burning of fossil fuels) stimulate photosynthesis, legumes will be able to generate more carbohydrates and thus support more root bacteria, perhaps gaining thereby a competitive advantage over other plants. This could be beneficial for legume crops, but it would also undoubtedly alter the mixture of species in natural plant communities and encourage the growth of leguminous weeds (such as kudzu in the southeastern United States and clovers competing with cash crops or lawn grasses).

Another area of current research is focused on the mechanisms that nature has worked out to shut down nitrogen fixation when it is not needed. We now know that some of the plant and bacterial genes controlling nodule formation and nitrogenase synthesis are turned off when large amounts of ammonia are already present in the soil.

As vital a process as nitrogen fixation is, it sup-

Nitrogen runoff from farms, lawns, and golf courses can stimulate massive blooms of algae and turn a pristine body of water into a fishless, green, mucky mess.

plies only 10 to 20 percent of the current annual nitrogen requirement for life on earth. The rest comes from recycling nitrogen that has already been fixed. Here, too, soil organisms play a major role.

Early on, as our planet's food chain began to evolve, a huge cast of soil creatures, collectively known as decomposers, evolved the capacity to obtain their nitrogen by consuming dead microbes, plants, or animals. Nitrogen is also recycled by a group of soil bacteria that use the hydrogen atoms of ammonia as an energy source, converting ammonia to nitrate in the process. Yet another group of bacteria, known as denitrifiers, feed on the nitrate for the oxygen it contains, rather than as a nitrogen source. They use the oxygen atoms as a substitute for pure oxygen and produce N_2 gas as a waste byproduct of respiration. Denitrification thus replenishes the atmosphere with N_2 and closes the loop of the nitrogen cycle.

Unfortunately, humans are now interfering with this cycle in a serious way. The rapid increase in the population of our species over the past few centuries has resulted in the need for a great deal of fixed nitrogen. To feed our crops, we initially relied on recycled nitrogen in the form of manure, but at the beginning of the twentieth century, scientists warned that unless another source of nitrogen fertilizer was found, food shortages were imminent. With World War I looming, nitrogen was also in demand for the production of trinitrotoluene (TNT) and other explosives.

So, during the first decade of the last century, the race was on to figure out how to do what the subterranean nitrogen fixers had been doing for billions of years: make a usable form of nitrogen out of N_2 gas. In the early 1900s, Germany had some of the most sophisticated chemistry laboratories in the world. Fritz Haber, an ambitious and gifted young scientist working at one of these facilities, was attracted to the problem and ultimately became the first human to fix nitrogen. Or, to be more precise, Haber was the first to do it without blowing up his laboratory—and with a yield of ammonia that made the process practical for commercial production. In 1909 he began a collaboration with an industrial engineer named Carl Bosch, and by 1910 the first nitrogen factory was up and running. The feared nitrogen crisis had been avoided.

Today, nearly a century later, the Haber process remains the only economically viable method for producing synthetic nitrogen fertilizer. Unfortunately, the process requires large amounts of energy, temperatures of about 930°F (500°C), and pressures of several hundred atmospheres (several hundred times the air pressure at sea level). Constructing a nitrogen-fertilizer plant thus costs hundreds of millions of dollars. The holy grail of today's nitrogen chemists is a biotechnology alternative—vats of nitrogenase churning out cheap fertilizer—but that goal remains elusive.

Despite the expense of the Haber process, the demand for fertilizer is so great that the amount of nitrogen fixed industrially in this way has been doubling about every six years since Haber first introduced his method. More than 90 percent of the fer-

Below: Like all animals, grizzly bears get their nitrogen by consuming other organisms. Bottom: Large amounts of fertilizer are used to grow food for animals destined for the slaughterhouse.

THOMAS MANGELSEN; MINDEN PICTURES

In most countries where incomes are rising, meat consumption is increasing too—as is the inefficient use of nitrogen fertilizers.

PAUL FUSCO; MAGNUM PHOTOS, INC.

Below: Nitrogen enters waterways in the manure of pigs and other farm animals. Opposite page: Planting alfalfa, a legume, is one way to add nitrogen to the soil without applying fertilizers.

RICHARD HAMILTON SMITH

The demand for fertilizer is so great that the amount of nitrogen fixed industrially has been doubling about every six years.

tilizer needs in the United States are met by man-made nitrogen fertilizer. The majority of this is used to grow crops to feed livestock rather than humans. Nutritionists and agricultural scientists have known for many years that meat is a much less efficient way to meet our dietary nitrogen (and thus protein) needs than is the direct consumption of fruits, grains, and vegetables. Despite this, in most countries where incomes are rising, meat consumption is increasing too—as is the inefficient use of nitrogen fertilizers.

Researchers estimate that at least one-third of the human population is currently being fed, directly or indirectly, with the help of the Haber process. Globally, more nitrogen is fixed by humans through this method than by all the naturally occurring microbial fixers in the soil. Yet only about one-third to one-half of the nitrogen we pour onto our farms, lawns, gardens, and golf courses each year is actually taken up by plants. Much of the rest, in the form of nitrate, leaks into groundwater, estuaries, and the oceans. A high level of nitrate in drinking water is toxic, especially to infants. Added to natural bodies of water, nitrate stimulates massive blooms of algae that clog the waterways, reduce clarity, and use up so much oxygen that few other aquatic species can survive alongside them. Nitrate from farmlands and factories in the central United States is currently draining through the Mississippi River and into the Gulf of Mexico; during some years, this creates a "dead zone" of several thousand square miles.

Recently, scientists discovered that atmospheric concentrations of nitrous oxide (N_2O), a gaseous by-product of the microbial denitrification process, have increased from about 290 to 310 parts per billion in the past fifty years, paralleling the human-caused increase of nitrogen on the land. Even in trace amounts, nitrous oxide can cause acid rain, contribute to the deterioration of the stratospheric ozone shield that protects us from ultraviolet radiation, and act as a very potent greenhouse gas—300 times more potent than carbon dioxide.

In response to growing environmental concern, many farmers have begun working with agricultural scientists to improve both the precision of nitrogen fertilizer application and the efficiency with which crop plants take up the nitrogen. Some farmers are adopting methods to "spoon-feed" fertilizer to their crops slowly, as the crops develop, rather than dump one huge application on the soil just before planting. One new technology, already being tested in some areas, is the use of global positioning satellites (GPSs) to create high-resolution "nutrient maps" of farm soils. As a farmer passes through his or her fields on a tractor, the GPS information is fed into the tractor's computer, and the amount of fertilizer applied, foot by foot, is automatically adjusted. Other research focuses on the genetic improvement of legumes and their nitrogen-fixing bacterial partners. The use of legumes as rotation crops is once again gaining favor. And some farmers include "trap crops" in their rotations—plants such as cereal rye and sudangrass, which have deep, prolific rooting systems that are able to take up nitrate before it leaches into groundwater. Finally, geneticists are hoping to reduce the nitrogen requirements of some of our planet's important food crops. My own research program includes a collaborative project with plant breeder Margaret Smith, also at Cornell, to develop varieties of corn that use nitrogen more efficiently.

Can the same human ingenuity that led to a process for fixing nitrogen help us find solutions to the problems we created by tampering with the nitrogen cycle? We know that our nitrogen-fixing activities of the past century have significantly increased the earth's capacity to support life, but we also know that if we want to sustain this life as well as protect our natural environment, we will need to come up with better, more efficient ways to manage the nitrogen we fix. □

Threads of Okin

ISHIGAKI MUNICIPAL YAEYAMA MUSEUM

Three weavers interpret their region's heritage.

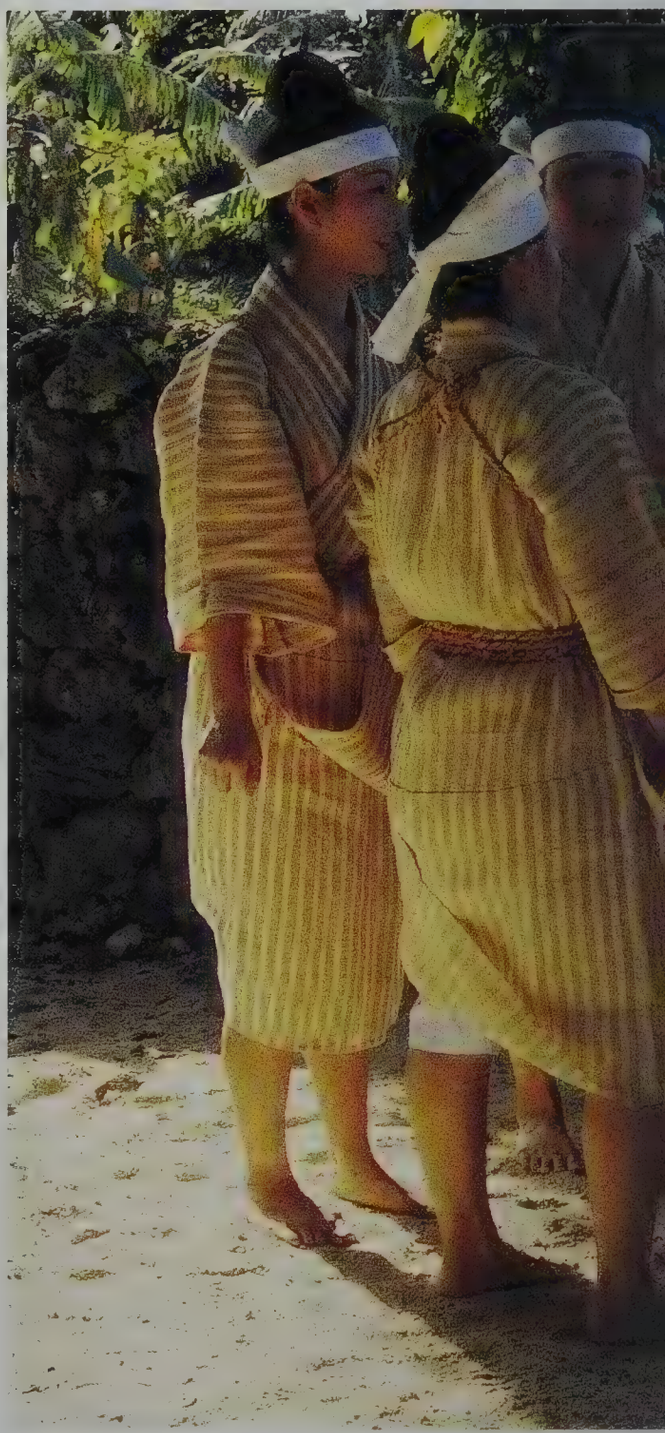
By Amanda Mayer Stinchecum

Above: From the early seventeenth to the twentieth century, ramie cloth was made in the Yaeyama Islands as tax payment. Below: Ramie cloth made by contemporary weaver Arakaki Sachiko.

TARUMI KENGO

Stretching from the island of Kyūshū southwest to Taiwan, the Ryukyu archipelago consists of about two hundred islands, some volcanic, the rest formations of coral. The majority make up Japan's southernmost prefecture, Okinawa. Typhoons regularly pummel this subtropical region, impartially buffeting old wooden houses and new buildings of stucco, glass, and poured concrete. Rain and salt spray drench sugarcane fields, rice paddies, jungle, and city streets. The soil is generally thin and poor, and on many islands the water table is too low for wet rice cultivation. More than 90 percent of the more than 1.3 million inhabitants are concentrated on the main island (also called Okinawa). Relying principally on income from U.S. military bases, government subsidies, and tourism, the prefecture is Japan's poorest. But the women boast the highest average life expectancy in the nation and the world.

During World War II, Allied bombing of the main island, culminating in the 1945 invasion of Okinawa, reduced the prefecture's capital city of Naha to rubble and destroyed most of the smaller towns and villages. An estimated 150,000 civilians died. Twenty-seven years of U.S. occupation followed before the territory reverted to Japanese sovereignty. Even now, some 25,000 American military personnel, along with their dependents, live and work on bases that occupy one-fifth of the main island. Fueling resentment against both the Japanese and the U.S. governments for acting without the consent of the Okinawans, this military presence creates bad feelings that are naturally exacerbated when servicemen commit crimes against local civilians. More than 4,700 incidents have been reported since 1972, with rapes of young girls and women



awan History

being among the most serious. Accidents that have resulted from military maneuvers—including 39 air crashes since 1972—are another cause of outrage.

Although Okinawans have not turned to the kind of violent nationalism that has arisen among some ethnic groups in Eastern Europe, South Asia, Southeast Asia, or Africa, they do assert their own identity, distinct from that of mainland Japan. Linguists recognize five separate languages within the archipelago, related to but different from Japanese. The indigenous religion, presided over primarily by women, incorporates elements of shamanism and animism. Aspects of household and village organization (particularly the prominent role played by women), together with Okinawan music, dance, literature, architecture, ceramics, textiles, and food,

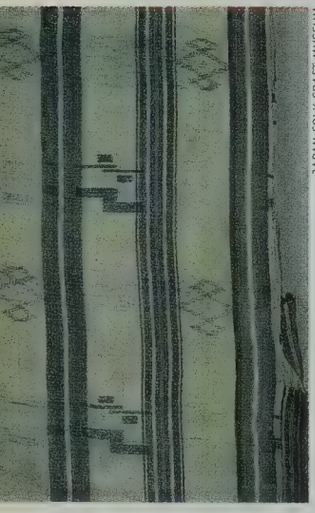
AMANDA MAYER STINCHECUM

On the island of Taketomi, in the Yaeyama Islands, women wait their turn to perform during their village's most important religious festival, Tanedori. Wearing robes of fiber banana cloth held in place with ropes of twisted straw (work clothes worn by village women until after World War II), they will enact the role of the hardworking farm-woman.

TARUMI KENGO

AMANDA MAYER STINCHECUM

Arakaki Sachiko, above, has revived the ikat technique for patterning ramie cloth in the Yaeyama Islands. Right: The cloth is laid in the sea for bleaching and to help set the dye. Below: Fine ramie cloth from the nineteenth century.



JAPAN FOLK CRAFT MUSEUM

form a multifaceted and fluid but unique heritage. Among these, cloth and clothing in particular have come to embody Okinawan ethnicity, both for the people of the islands and for others beyond their coastal reefs.

Records of local textiles go back to the Ming dynasty (1368–1644), when China extended its cultural and economic hegemony to the Ryukyu Islands, legitimating three kings of the main island in exchange for their submission to the Ming emperor. In 1372 the first Ryukyuan emissaries reached Nanjing, where they presented their tribute payment of local products: sulfur, horses, and ramie cloth, a fabric woven from the bast fibers of an indigenous plant in the nettle family.

Under this benign arrangement, the kingdom of Ryukyu (unified in 1429 under the court at Shuri, now part of the city of Naha) became a thriving entrepôt for trade between Japan, Korea, China, Siam, Sumatra, Malacca, and other Asian states. But in 1609, forces from Satsuma, a Japanese feudal domain in southern Kyūshū, invaded the islands and took the king hostage. Ryukyu's autonomy survived in name only. Two years later, Satsuma demanded its own annual tribute, including some 75,000 bushels of rice and 19,000 rolls of cloth (each roll was about thirteen yards long and sixteen inches wide—enough to make one kimono). Sixteen thousand of these rolls were ramie; the remaining 3,000 were *bashōfu,* made of fibers taken from the leafstalks of the *ito bashō,* or fiber banana plant, a relative of the edible banana. These crisp, breathable fabrics are highly valued even today for kimonos worn during Japan's hot, humid summers.

To meet Satsuma's demands, the Shuri monarchy levied taxes on the Ryukyuan people. Most of these taxes were payable in grain. But on Kume Island (west of the main island) and in the Outer Islands (the island groups of Miyako and Yaeyama, at the southwestern end of the archipelago), these took the form of a poll tax. More than half were to be paid in cloth, mainly ramie. Local officials strictly—and sometimes cruelly—controlled all aspects of production. Although in principle both men and women bore the burden of grain and cloth payments, in practice yarn making, dyeing, and weaving were allotted to women, on the basis of skill and age. This system continued even after 1879, when Japan's Meiji government forced Ryukyu to submit to Japanese sovereignty, abolished the Ryukyuan monarchy, and annexed the islands to create Okinawa Prefecture. (The poll tax was finally eliminated in 1904.)

Known as Yaeyama *jōfu* (fine cloth), the finest ramie weaves came from the Outer Islands. Despite the hardships and humiliations under which they labored, the women of this area expressed through songs the joy, close to awe, they felt toward the act of making a beautiful piece of cloth as an offering to the king. (In fact, the cloth was presented to the local administrative office.)

This feeling—that dyeing and weaving, and the resultant cloth, are sacred offerings—permeates the work of Arakaki Sachiko, a contemporary weaver on Ishigaki Island.

Though born and raised in the town of Ishigaki, the administrative center of the Yaeyama Islands, **Arakaki Sachiko** grew up unaware of the fine textiles made by her ancestors. On a trip to Tokyo in the early 1970s, however, she visited the Japan Folk Craft Museum and discovered the vibrant colors and patterns of ramie cloth made during the era of the poll tax.

The bold yet delicate designs resulted from the ikat technique, a painstaking method of resist dye-

ing in which selected segments along lengths of yarn are tightly bound to prevent the dye from penetrating. When these yarns are woven together on the loom, the combination of dyed and undyed segments creates patterns whose outlines are more or less blurred according to the skill and intent of the weaver. In the Yaeyama Islands, true ikat was abandoned in the early twentieth century in favor of a quicker and cheaper method—applying a thickened, dark red-brown dye directly to the yarns—that resulted in a more uniform, hard-edged pattern.

After studying in Naha, Arakaki returned to Ishigaki and single-handedly recreated the old ikat method of making Yaeyama *jōfu*. She also revived

Ryukyuan royalty wore robes of dyed fiber-banana cloth.

the rich palette of colors: the blues of indigo, a vivid yellow from the *fukugi* tree, the pinks and reds of sappanwood and safflower. Eventually she received a commission to reproduce, for display at the Ishigaki Municipal Yaeyama Museum and the Japan Folk Craft Museum, two sets of the very robes in the Tokyo collection that had originally inspired her work. She says the luxury of working for the first time exclusively with handmade yarn—scarce and costly—taught her "the blessedness of the yarn itself."

The project proved to be a test of fire. Using plant dyes, which are notoriously unpredictable, Arakaki labored to duplicate the bold patterns and vivid colors of the originals—a task much more difficult than improvising. On more than one occasion, she had to start over from the undyed yarn when she couldn't correct a weaving or dyeing error.

Given a new sense of her own potential, Arakaki has since experimented with fresh combinations of colors derived from plants, nearly all from Okinawa—brilliant greens, velvety grays, golden ochres, pinks and reds, every shade of indigo blue. In June 1995 she exhibited her work in Tokyo at Wakō, a department store known for refined, very Japanese taste. This solo show provided a rare opportunity for an Okinawan artist to reach a discerning mainland audience. The experience challenged Arakaki to raise her work to a still higher artistic level.

Okinawans believe clothing envelops the spirit, preventing its escape from the body. Arakaki's labor is an act of consecration, embracing her own spirit. The airy membranes she weaves, fashioned into the loose robes of the islands, protect the soul of the wearer.

The earliest detailed descriptions of Ryukyuan cloth and clothing date from the fifteenth century. Shipwrecked Koreans who washed up on the shores of Yonaguni, the westernmost of the Yaeyama Islands, reported that the islanders—all commoners—cultivated, wove, and wore only ramie. Silk and cotton production was introduced into the Ryukyus from China in the sixteenth century, but the use of these fabrics was long restricted to the elite classes. As the demand for ramie for tribute, tax, and trade increased, the monarchy forbade commoners to wear this fabric as well. Clothing made from *bashōfu* (fiber banana cloth) took its place. Eventually women, children, and men of all classes—kings and queens, court officials and landowners, and the poorest farmers and fisherfolk—all adopted *bashōfu*.

Robes of fiber banana cloth dyed brilliant yellow and scarlet, some of them ikat-patterned, were worn by Ryukyuan royalty. The glossy blue-black, green, or ivory garments of court officials were so fine and lustrous that the untutored eye now mistakes them for silk. *Bashōfu* garments worn by the court and aristocracy were made in the capital, Shuri. Commoners wore coarser robes the color of dried grass, plain or with brown stripes or checks; they were forbidden to wear ikat. Even today, although nearly all Okinawans wear Western-style clothing, they often don *bashōfu* garments for local festivals and other celebrations.

The fiber banana familiar in the Ryukyus has

TARUMI KENGŌ

Arakaki uses local plant products, including gardenia fruits and annatto, to dye her ramie cloth.

AMANDA MAYER STINCHECUM

TREASURES FROM THE SHO FAMILY INHERITANCE, NAHA

Taira Toshiko, top right, separates the layers of a fiber banana stalk—the first step in making yarn. Below right: A scarlet robe of fiber banana cloth *(bashōfu)*, patterned with a geometric float weave, made for Ryukyuan royalty during the nineteenth century. Bottom right: A member of the *bashōfu* cooperative in Kijoka boils strips of fiber banana with ash lye. This softens the pulpy part, which is then scraped off. The resultant ribbons of cellulosic fiber will be split into yarn.

sometimes been regarded as a separate species or variety *(Musa liukiuensis* or *M.* x *sapientum* var. *liukiuensis)*, but it is probably best classified as *M. balbisiana* and most likely was introduced from Southeast Asia. Throughout the Ryukyus, this treelike plant, with its large, pliant leaves shredded by the wind, creates pools of shade next to tile-roofed wooden houses and forms windbreaks around cultivated fields. It does not grow wild, however—a sign that it is not truly indigenous. Exactly when and how the fiber banana reached the islands remains a mystery; its cultivation is not mentioned in historical documents until 1546.

Following Japan's annexation of Okinawa, fiber banana cloth became fashionable for summer kimonos on the mainland, and it was produced in villages throughout the prefecture. Kijoka, in the northern part of Okinawa Island, shared in this work. The ikat technique was introduced into Kijoka in the late nineteenth century. *Bashōfu* developed far beyond the simple cloth that had been the earlier heritage of Ryukyuan village life. Because many of the men left the village in the early decades of the last century to do construction work in Naha, women became the primary practitioners of the art. By the early 1940s, hundreds of kimono lengths of golden-brown cloth with rich brown and deep indigo motifs were being sold at Mitsukoshi, an elegant department store in Tokyo.

As Japan intensified its war effort, Okinawa's weaving enterprise ground to a halt. Volunteers from Kijoka joined many other Okinawans at an aircraft factory in the mainland Japanese town of Kurashiki, midway between Osaka and Hiroshima. Kijoka weaver **Taira Toshiko** went along. At the war's end, uncertain of Okinawa's fate, Taira remained in Kurashiki for another year. There she came to the attention of Tonomura Kichinosuke, a weaver and folk-craft proponent who later founded the Kurashiki Folk Craft Museum. He urged her to return to Kijoka and preserve the legacy of Ryukyuan *bashōfu*.

Taira followed his advice, and the workshop she

established in Kijoka in 1962 has flourished under her quiet direction. Taira was instrumental as well in the founding of a *bashōfu* cooperative in Kijoka. In 1999 the Japanese government designated her a Living National Treasure for both her textile art and her leadership in reviving Kijoka's *bashōfu* industry. Weavers on several of the Yaeyama Islands have also carried on local traditions of making and using fiber banana cloth. Some have incorporated the yarns into innovative silk and cotton textiles.

In 1999, Taira Toshiko was named a Living National Treasure.

Including 100 yarn makers, about 150 people participate in the textile cooperative. To produce the yarn, the women cut down the mature plants and strip off layers from the sheathlike leafstalks, sorting them into piles to be made into fine, medium, and coarse cloth. They soften the fiber by cooking it with lye. The most demanding part of the yarn-making process—splitting the gleaming ribbons of fiber into fine strands, then tying the strands end to end to form a continuous yarn—is performed by some of the oldest members of the village, nimble-fingered women whose dimmed eyesight prevents them from doing the actual weaving of the intricate ikat patterns. Kinjō Nabe, who died recently at age 106, continued to make yarn until shortly before her death.

The average age of the women in Taira's own workshop is about 60, while the apprentice weavers working nearby in the Kijoka textile cooperative's hall are considerably younger—a healthy sign for the future of the craft. Taira spends most of her time with the apprentices, walking from loom to loom and occasionally making a gentle suggestion to a weaver intently bent over her work. Extremely shy and increasingly frail, she leaves most of the administrative responsibilities to her able and articulate mainland-born daughter-in-law, Mieko.

Even with a drastic decline in the number of

TARUMI KENGŌ

TARUMI KENGŌ

Below: *Bashōfu* woven for fine summer kimonos by Taira Toshiko and the women of her workshop. The subtle warp-and-weft ikat pattern was dyed blue and brown with indigo and the woody stalks of *teichi*, a member of the rose family.

JOYCE PENDOLA

The main islands of Okinawa Prefecture

TARUMI KENGŌ

Makishi Tamiko, above, works in silk, sometimes incorporating other fibers to vary the texture. Scarves and shawls, below, reflect her contemporary aesthetic.

Japanese women who wear kimonos, the cooperative sells all the cloth it produces—about 270 rolls a year. A roll from Taira's own workshop sells in Tokyo for upwards of $15,000—"to some," according to Mieko, "because it is made by a Living National Treasure, but to a few because they really love it." Mieko also observes that if it weren't for souvenir items—neckties, wallets, decorative mats—this modern cottage industry, like so many others in Japan, would be dying out.

A few years ago, Taira made a special collection dyed in the vivid reds, yellows, and greens of the Ryukyuan court. But she prefers the modest style traditional in Kijoka, in which the blue and brown of local vegetable dyes complement the natural golden color of the fiber. Taira has rescued, nurtured, and refined this cloth. Today it is an emblem of Okinawa itself.

In fact and sensibility, **Makishi Tamiko** is a weaver whose world is entirely urban. Her father, Nakasone Seizen, collected, reconstructed, and interpreted Okinawa's languages and ancient poetry. One of Okinawa's most cherished scholars, he remains a great influence on her work. Like many Okinawans, Makishi fled her home in the capital to

MAKISHI NAMI

escape Allied bombing, spending the war years in her father's home village of Nakijin. Otherwise she has lived her whole life in cities—first Naha, then Tokyo (where she attended art school), and now Urasoe, adjacent to Naha.

A profoundly private person, Makishi has nevertheless played a leading role in encouraging and displaying the work of independent weavers on Okinawa's main island. In the past five years, her solo shows in small galleries throughout Japan—often with installations designed by her husband, painter Makishi Tsutomu—have gained her quite a following.

Some weavers in Okinawa actively seek ways to adapt their textiles to contemporary clothing, but

One cocoon can yield a silk filament 1,500 yards long.

Makishi is reluctant to do so. Handmade fabrics are both costly and fragile. The wearer faces the possible discoloration or fading of natural dyes, laundering problems, the weakening of the delicate fibers because they've been pierced by sewing-machine needles—as well as the prospect of spending $2,000 or $3,000 to commission an outfit subject to the whims of fashion. More significant for Makishi, creating Western-style clothes necessitates cutting into the natural borders of the woven rectangle, a destructive act minimized in the making of traditional Japanese clothing. To avoid this, while ensuring that her fabrics will be worn, Makishi has decided to concentrate on shawls and scarves.

TARUMI KENGŌ

Once a weaver of silk for kimonos, Makishi has stayed with silk. But instead of using the inelastic, characterless, machine-reeled silk yarn produced by mainland factories, whenever she can get fresh cocoons she reels her own silk, pulling out a number of fragile filaments to form a glistening thread (from one cocoon, agile fingers can entice a single filament 1,500 yards long). Sometimes Makishi inserts fiber banana or ramie yarn into the silk web, skillfully weaving in a crisp line or two, or she crosses silk warps with crinkly ramie wefts to make a new texture, choosing with deliberation the hue and material of each thread.

Makishi's subtle colors and textures evoke the subdued grays, tans, and dark blues of kimonos

worn by the women and men in her family during and after the war. One of her prized possessions, a man's golden-tan-and-white striped summer kimono of fiber banana and cotton, belonged to a favorite uncle—something of a dandy, she says. Very occasionally, Makishi will dye an entire shawl a single, startlingly intense color, but her palette tends toward white, beige, brown, gray, and sometimes yellow or indigo blue, worked into delicate shadings of stripes, checks, or wide bands. These may be shot through with a single line of light blue (from the *kusagi* berries she grows on her terrace) or some other contrasting hue, so inconspicuous that it might go unnoticed except when the wearer turns her head and sees it for the first time, from a few inches away, in the shawl that lies on her own shoulder.

For the past few years, Makishi has been working with carbon ink (so-called India ink or Chinese ink), dyeing skeins of lustrous silk yarns pale silver, glossy charcoal, and every shade in between. Calligraphers and painters know that some carbon ink has a bluish tinge, some is brown, some a more neutral gray. Makishi exploits this infinite rainbow. Her use of ink—the essential substance of the scholar's work in East Asian cultures, more than just a means of recording words—is a conscious tribute to her father's memory.

Light as clouds, translucent as fog, or gleaming like a sheet of silver or copper leaf, Makishi's weavings are completely contemporary. Her work is, above all, a representation of her inner life. "From the time the umbilical cord is cut and tied, human beings begin the search for the thread that ties their lives together," she has written of her own connection to fashioning cloth. Her art incorporates the old ways of yarn production and dyeing, of reeling and degumming silk, into a new tradition of her own making. □

Spools of silk yarn, below, display some of the colors Makishi Tamiko has obtained from vegetable dyes. Makishi's current work utilizes a variety of carbon inks, from which she coaxes purple, brown, and bluish tones as well as shades of gray from silver to charcoal.

Ghost Stories From the Ice Age

Some plants are haunted by large mammals from another era.

Story by Connie Barlow ~ Illustrations by Michael Rothman

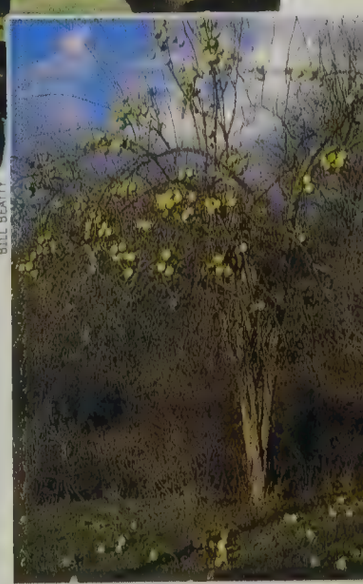
"In the shadows along the trail," wrote paleoecologist Paul Martin in 1992, "I keep an eye out for ghosts, the beasts of the Ice Age. What is the purpose of the thorns on the mesquites in my backyard in Tucson? Why do they and honey locusts have sugary pods so attractive to livestock? Whose foot is devil's claw intended to intercept? Such musings add magic to a walk and may help to liberate us from tunnel vision, the hubris of the present, the misleading notion that nature is self-evident."

A mere 13,000 years ago, near the end of the Pleistocene Epoch (which began 1.6 million years ago), fruiting plants of the Western Hemisphere that had long relied on big animals to distribute their seeds suddenly lost these allies. Although some scientists believe diseases or climatic change may have been factors, a growing body of evidence supports Paul Martin's hypothesis, first advanced in the 1960s, that newly arriving humans equipped with formidable stone-tipped spears were responsible for wiping out the large Pleistocene mammals that had roamed forests, deserts, and plains. Within a thousand years of the first evidence of this hunting culture in the Americas, the mastodons and mammoths, tall camels, giant armadillos, and ground sloths—and the giant bears, cats, and wolves that stalked them—had all disappeared.

These extinct American herbivores once dispersed the seeds of such big-fruited plants as honey locust, Kentucky coffee tree, and Osage orange, all of which produce fruits that no native animal today regards as food. Now the seeds either rot with the pulp or sprout too close to the parent tree. Avocado trees yield fruit with an outlandishly large pit that no native gullet can accommodate. In addition to bearing these "anachronistic" fruits, some trees display defenses that are equally out of step with current conditions. Mesquite, hawthorn, and honey locust protect their trunks or lower branches with long, sturdy thorns that now seem unnecessary.

How have these fruiting plants managed to survive for 13,000 years without their dispersal partners? An individual plant can keep sending up root suckers that allow it to persist for hundreds, even thousands of years. Another way is by entering into new partnerships: humans now plant seeds and saplings in widely scattered locations. Yet these plants still proclaim, by the very structure of their fruits, seed coats, and armaments, that they are adapted for life in a vanished world.

ALWIN E. STAFFAN; NATIONAL AUDUBON SOCIETY, PHOTO RESEARCHERS, INC.



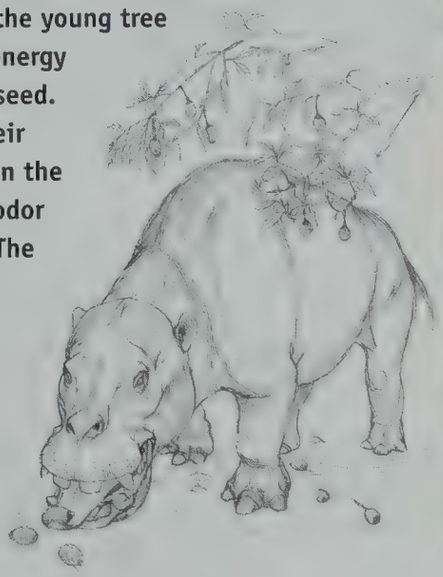
BILL BEATTY

OSAGE ORANGE *(Maclura pomifera)* could have been more accurately named American breadfruit; the color and fibrous texture of this New World fruit closely resembles its tropical Asian counterpart. The fruit is, however, shunned by humans and all mammals native to North America, where the tree was once common in woodland meadows and at prairie edges. After losing its dispersal partners, which presumably were large herbivores, Osage orange became increasingly rare. The hard, fibrous spheres, above, frustrate deer and cattle, which lack upper incisors. By the time Europeans arrived, the tree's range was confined to just a few river valleys in what is now eastern Texas. Ranch horses there do consume the fruit after it has fallen, which suggests that early native horses of the Pleistocene, opposite page, may also have eaten it.

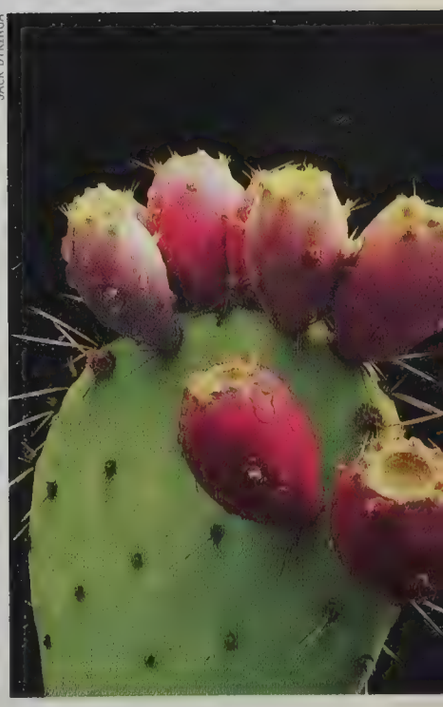
ROBB AND ANN SIMPSON

A MASTODON plucks pods from a honey locust tree, below. For more than 20 million years, the honey locust *(Gleditsia triacanthos)* lured big beasts to disperse its tough, tooth-resistant seeds by embedding them in sweet, protein-rich pods. Native to the central United States, this tree of the forest edge also sported ferocious thorns on its trunk and lower branches, left, preventing the elephants from stripping bark—and thus killing the tree—while they browsed for seed pods. No contemporary seed dispersers can reach the pods, and today the thorns are probably superfluous. We now plant this sturdy, drought-resistant tree along urban sidewalks and in suburban parking lots. The fallen pods can be a nuisance to pedestrians, though, and the sharp thorns are dangerous, so domesticated varieties tend to be male (podless) and thornless. Among older plantings in city parks, however, one can find female trees with pods, their trunks heavily armed with mastodon-proof thorns.

WILD AVOCADOS produce nutritious, energy-rich fruit, right, with one very large and dense seed that contains bitter poisons. This small tree *(Persea americana)* lives in shady tropical forests. During its first few months of growth, while seeking out shafts of sunlight, the young tree depends upon the energy stored in the huge seed. Adult trees drop their drab-colored fruit on the ground, where the odor attracts mammals. The largest living fruit-eaters of tropical America are several species of tapir, which eat around the seed or spit it out. Thirteen thousand years ago, however, the hippopotamus-like *Toxodon,* above, would have swallowed whole avocado seeds and defecated them in other parts of the forest.



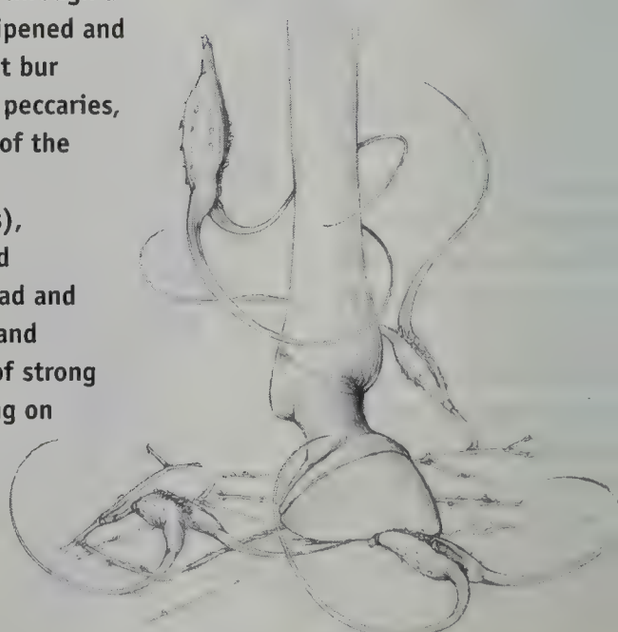
AN AMERICAN CAMEL of the Pleistocene finds cactus fruit easy to reach, right. The camel clan originated in western North America before spreading into Eurasia and Africa. Equipped with long legs and neck, *Camelops* would have been an ideal dispersal partner for tall species of prickly pear *(Opuntia)* in the deserts of North America. Today the fruit of these cacti, far right, is plucked by nonnative livestock or, once it withers and falls, eaten by scavenging coyotes and foxes. The small, tough seeds survive in their dung and soon sprout.

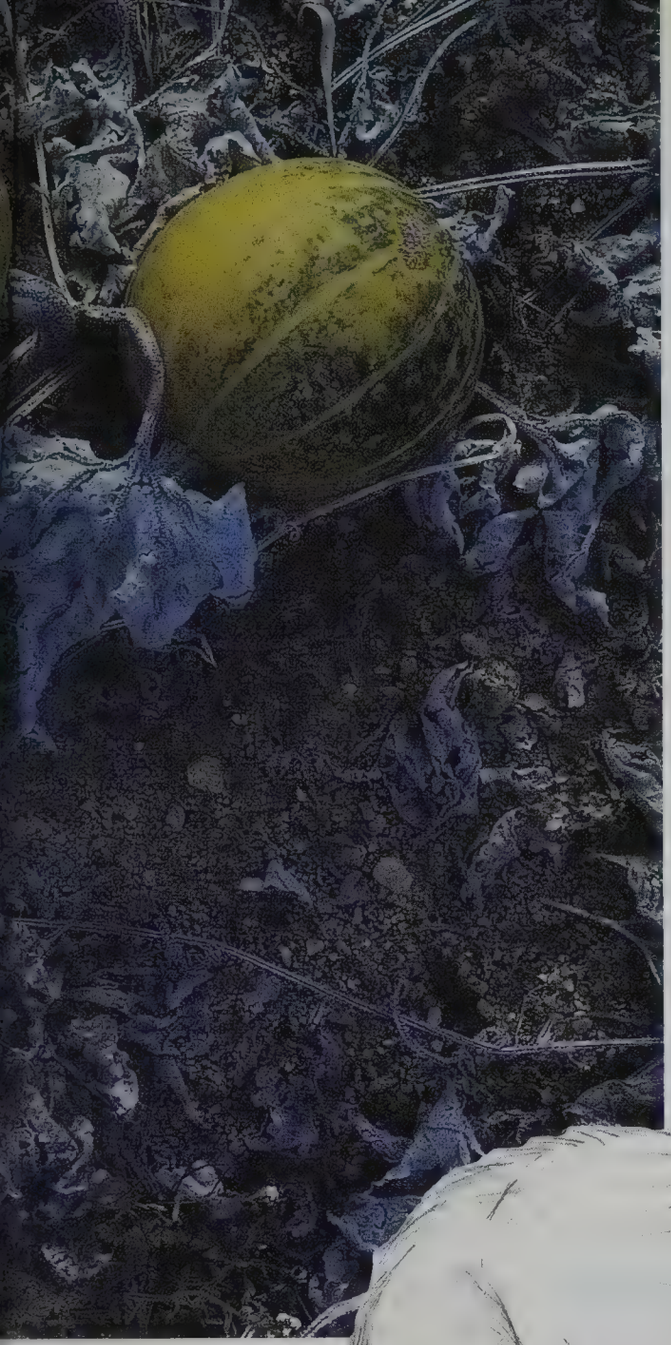


STEPHEN TRIMBLE

DEVIL'S CLAW *(Proboscidea)* grips the hoof, right, of an extinct American horse. In this re-creation, the animal has walked through a patch of devil's claw, or unicorn plant, after the fruit has ripened and split open and the leaves have died back. Because the giant bur cannot attach to the slender limbs of deer, pronghorn, and peccaries, the plant's range probably diminished after the extinction of the large Pleistocene mammals. Following the introduction of domesticated horses and cattle (and, later, of farm tractors), however, devil's claw rebounded, and it is now a widespread agricultural pest. The hard fruit, left, is shaped like the head and trunk of an elephant. As it ripens, its green skin blackens and dries; eventually the "trunk" pops open to become a pair of strong but flexible pointed tongs. Some seeds drop from the casing on contact with the disperser. The remainder are released when the swollen part of the woody bur has been trampled or crushed.

STEPHEN TRIMBLE





Thirteen thousand years ago, some big-fruited plants of the Western Hemisphere suddenly lost the animal allies that helped disperse their seeds.

GOURD-BEARING VINES *(Cucurbita)*, left, precursors of domesticated squashes and pumpkins, are found in dry washes and along roadsides in Mexico and the U.S. Southwest. Today they are spread by floodwaters and also carried on tire treads and in the blades of road graders. During the Pleistocene, the desert-dwelling Shasta ground sloth *(Nothrotheriops shastensis)* would have eaten the ripe gourds in autumn, below. Because the pulp is bitter (probably a defense against marauding insects), any animals eating large quantities of wild *Cucurbita* fruit may have had to consume clay to adsorb the toxins.

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AT THE MUSEUM

The Art of Worship

For millions of Hindus in India, religion interweaves private worship, public ritual, and ephemeral art.

Story and photographs by Stephen P. Huyler

Completing the morning's *kolam* in Tamil Nadu

It is dark as Padmasini Ramachandran steps between the sleeping bodies of her children and opens her front door. Just as she does every morning, she pours water from a small brass pot into her hand and sprinkles it over the dirt beneath her feet, making it firm enough to draw on. Bending straight from her waist, she takes a large pinch of rice flour from a little metal bowl and quickly drops it onto the ground, followed by another and another, all evenly spaced, until she has created a diamond-shaped grid of white dots about five feet long on each side. Then, with further pinches of flour, she deftly draws thin white lines between the dots—some straight, some curved—rapidly transforming this patch of earth into the petals, leaves, stamens, and stem of a lotus blossom. Because it is a special festival day honoring the gods, Ramachandran fills in her picture with colored powders before going inside to awaken her family and prepare breakfast.

In front of each doorway, all the way down the block and beyond, other women are creating *kolams* (known as *rangoli* or *rangavalli* in other parts of India)—decorations intended to protect home and family from evil and to encourage good fortune. Every day,

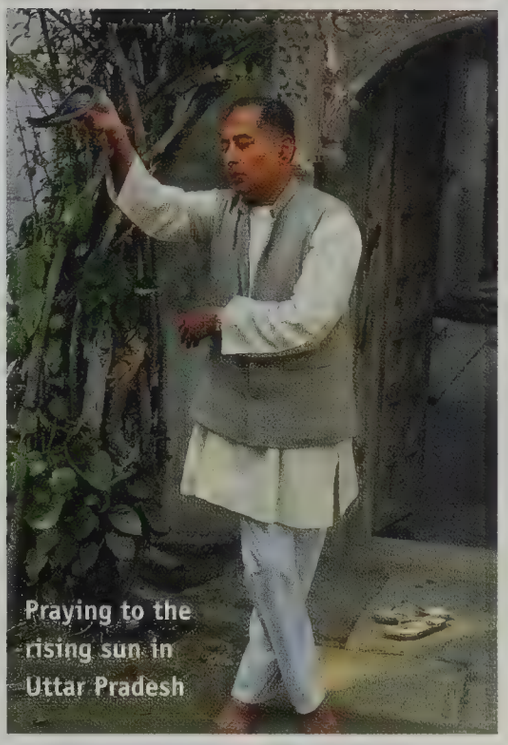
following a centuries-old tradition, women in more than a million homes in this southern Indian state of Tamil Nadu draw a fresh *kolam*. They pride themselves on never repeating a design.

Each drawing is ephemeral. As the day begins and family members come out of the house and into the street, they walk over the *kolam*, smudging the design. Bicycles, scooters, bullock carts, cars, and buses all rapidly eradicate the artwork; within an hour, all traces of it are gone. To an outsider, the women's efforts might seem to be a frustrating waste of time, but to the artist they represent a moment of creativity, solace, and spirituality.

Most of India's billion citizens are Hindus, members of a religion of remarkable diversity. Hinduism is polytheistic, and although its adherents may believe in an all-encompassing, indivisible being—similar in many ways to the god of Christians, Jews, and Muslims—they also believe that the many aspects of the divine may be viewed and worshiped through particular gods and goddesses that embody different aspects of the cosmos. Just as creation has innumerable facets, so Hinduism has innumerable deities, and the personalization of gods and goddesses makes possible an intimate relationship with the divine.

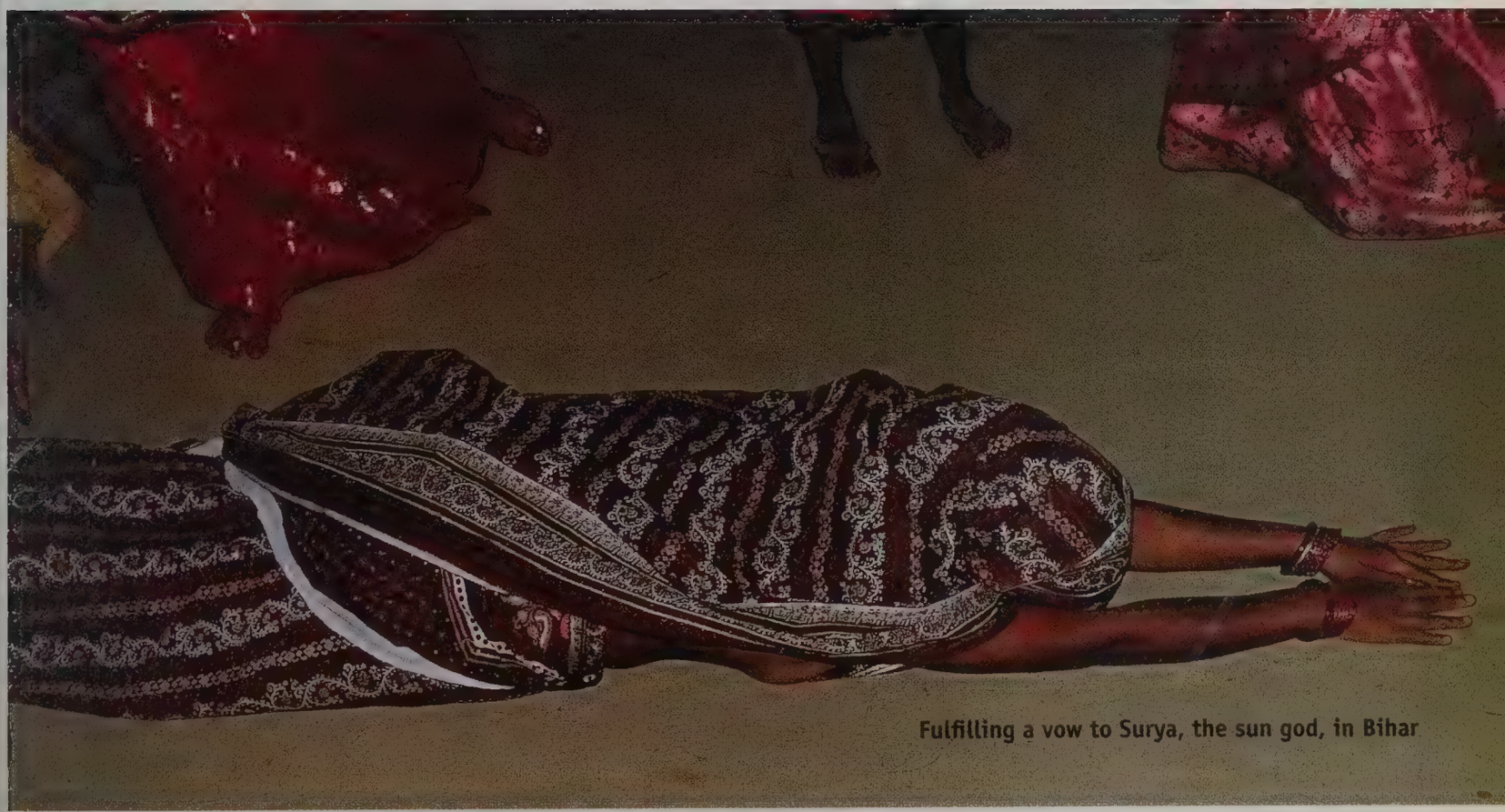
Hinduism is the world's third largest religion, involving one in every seven human beings. Unique among all major religions in that it does not proselytize, Hinduism also does not profess one right way, one set of beliefs, or one correct system of ethics. Young Hindus grow up learning to follow the tenets and customs of their parents but are encouraged to decide for themselves which primary gods or goddesses they find inspiring. This right of personal choice of deity means that although young adults continue to practice many family rituals, they also conduct their own private worship in whatever manner seems most beneficial to them.

The exhibition **Meeting God: Elements of Hindu Devotion** opens in Gallery 77 on September 8, 2001, and runs through February 24, 2002.



Praying to the rising sun in Uttar Pradesh

Beliefs may be individual, but rituals tend to be observed in common with large portions of the population. Ramachandran rises each morning to create her beautiful *kolam* just as her mother, grandmother, and great-grandmother did before her. Yet within the confines of this age-old ritual is the



Fulfilling a vow to Surya, the sun god, in Bihar

expression of her own personality, her individual creative communication with the divine. Similarly, throughout India, Hindus begin each day with rituals of devotion. Countless millions pray to the rising sun, considered masculine, while standing in or pouring water, viewed as feminine. In acknowledging the two, they also acknowledge the One, for in Hinduism the supreme deity is the absolute complement of opposites—dark and light, wrong and right, good and evil. By beginning each day in such ways, Hindus attune themselves with the universe and validate their place within it.

For thirty years, Stephen P. Huyler, a cultural anthropologist and photographer, has conducted field research in India on sacred art and rituals. He has worked extensively with museums exhibiting Hindu art; the exhibition "Meeting God: Elements of Hindu Devotion" is based on Huyler's book of the same name (Yale University Press, 1999).

MUSEUM EVENTS

STEVE McCURRY

***Pooja stahl* (prayer area), Raaga Entertainment Superstore, Jackson Heights, Queens (from an exhibition of photographs by Steve McCurry of Hindu, Sikh, and Jain shrines in the New York metropolitan area). Gallery 77 Annex, September 8, 2001, through February 24, 2002.**

SEPTEMBER 4, 5, AND 6

Central Park field trips: A series of eight bird walks led by Museum naturalists. Tuesdays (beginning September 4, with Stephen C. Quinn), Wednesdays (beginning September 5, with Joseph DiCostanzo), and Thursdays (beginning September 6, with Harold Feinberg).

SEPTEMBER 12 AND 22

Urban forest walking tours: Central Park (September 12, 8:30–11:00 A.M.) and Palisades National Natural Landmark (September 22, 10:00 A.M.–1:00 P.M.). William Schiller, Museum botany lecturer.

SEPTEMBER 19

Lecture: "Wildlife of India." Naturalists Hashim Tyabji and Toby Sinclair. 7:00 P.M., Kaufmann Theater.

SEPTEMBER 22

Field trip: "New York City Historic Sites and Their Geological Settings." Geologist Sidney S. Horenstein, coordinator for Museum environmental programs. 9:00 A.M.–5:00 P.M.

SEPTEMBER 28

Lecture: "The Story of the Man Who Made the Map That Changed the World." Author and BBC broadcaster Simon Winchester. 7:00 P.M., Kaufmann Theater.

SEPTEMBER 30

Free daylong program: "Reflections of Our Spirit," in conjunction with the exhibition "Meeting God: Elements of Hindu Devotion." Lectures on religious architecture and on traditional arts with religious symbolism; performances of music and dance; Indian food. 11:00 A.M.–5:30 P.M., Kaufmann and Linder Theaters and Leonhardt People Center. For details, call (212) 769-5315.

DURING SEPTEMBER

Additional field trips, walking tours, and workshops for children and adults, both inside and outside the Museum. For more information, call (212) 769-5200.

Planetarium courses: "How to Choose a Telescope"; "Stars, Constellations, and Legends"; and many others. For complete course descriptions, visit www.amnh.org/hayden.

Films at the IMAX Theater: *Lost Worlds: Life in the Balance* (biodiversity and the need for conservation); *Shackleton's Antarctic Adventure* (the dramatic story of the 1914–17 British Imperial Trans-Antarctic Expedition); and *Bears* (natural history of the grizzly, polar bear, and various other species).

The American Museum of Natural History is located at Central Park West and 79th Street in New York City. For listings of events, exhibitions, and hours, call (212) 769-5100 or visit the Museum's Web site at www.amnh.org. Space Show tickets, retail products, and Museum memberships are also available online.

Museum Friends Support Science Education and Increase Their Retirement Income

Looking back on his career as an executive at Simon and Schuster, Jason Berger says, "One of my proudest achievements was the distribution of Little Golden Books to supermarkets and pharmacies across the country, where they found their way into the hands of millions of young children who otherwise might have had little exposure to children's literature."

Several years ago, their wish to support science education prompted Jason and his wife Susanna to include the American Museum of Natural History in their wills. Then, last year, they discovered charitable gift annuities.

A gift annuity is a way to support the Museum and provide a lifetime annuity to one or two people aged 55 or older. When appreciated stock is used to fund the plan, there can be substantial capital gains tax savings.

According to Susanna, *"Because we can give and receive income for life, this is an ideal way for us to provide now part of the gift we want the Museum to have in the future. In fact, we like gift annuities so much, we plan to do one every year!"*

Here are sample rates and benefits for one person with a $10,000 gift:

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80	8.9%	$4,652	$890
85	10.4%	$5,046	$1,040
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For more information, please call (800) 453-5734 or reply by mail to: Office of Planned Giving, American Museum of Natural History, Central Park West at 79th Street, New York, New York 10024-5192

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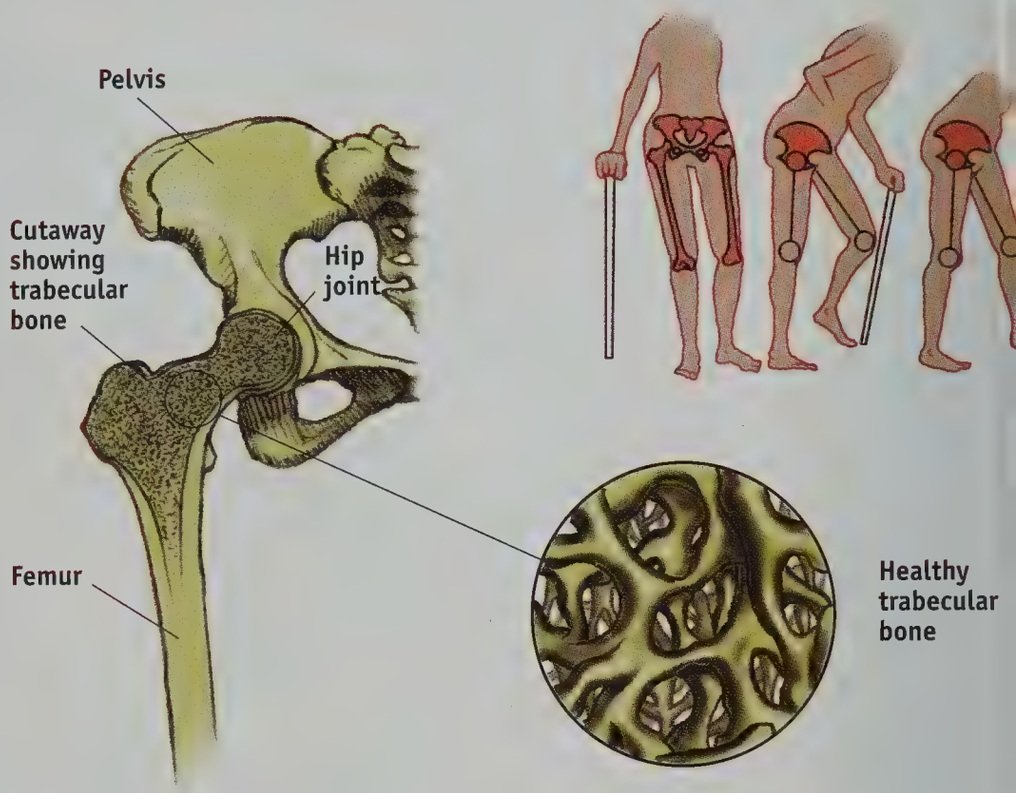
By Adam Summers



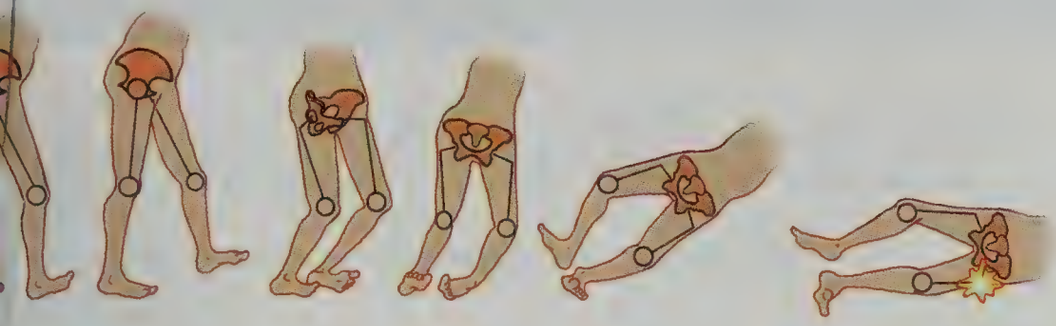
At about thirty years of age, the human skeleton is as heavy and strong as it will ever get. Then comes the downhill slide that for many people ends in osteoporosis (severe bone loss), crushed vertebrae, and fractured hips and wrists. But through studies of the internal architecture of bones and the ways they can fail, orthopedic biomechanics is setting a course for preventive measures and new treatments.

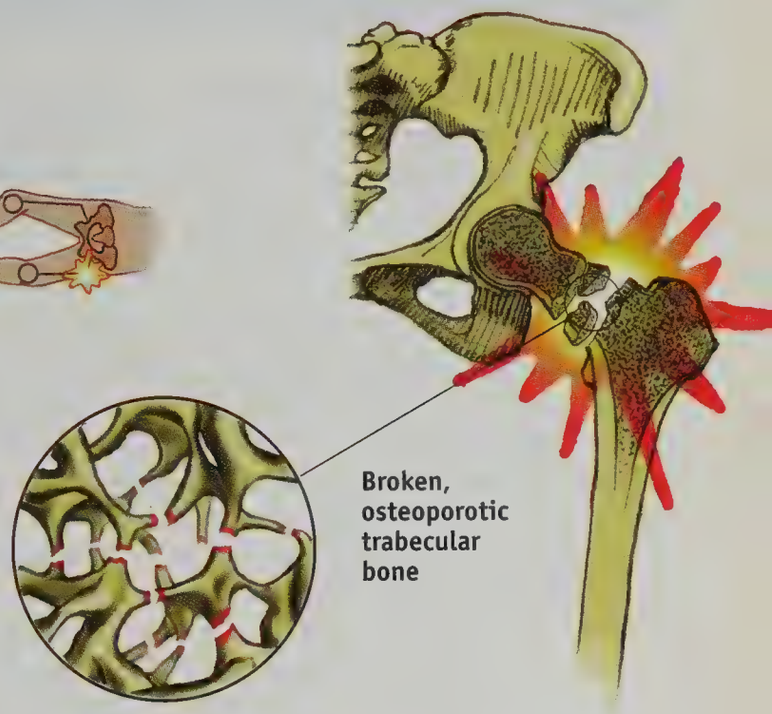
A typical bone consists of a hard outer shell surrounding a cavity filled with soft marrow tissue. Made of what is called cortical bone, the outer shell is remarkably thin. In the thighbone, or femur, for example—the longest, strongest bone in your body, running from the hip to the knee—the shell's thickness ranges from just two to eight millimeters. For most of the femur's length, the cavity is filled with fatty yellow marrow. At both ends, however, the last few inches of cavity are occupied by a meshwork of thin, mineralized struts called trabecular bone. The pores of this bone are filled with red marrow, which produces blood cells. Surprisingly, this bony filigree, which may fill in 30 percent of the open space, is responsible for most of the bone's overall strength.

The struts of trabecular bone are only about half as thick as pencil lead; their structural importance comes from their orientation and interconnections. The beauty of the arrangement of trabecular bone was noted in 1866 by a Swiss engineer, Karl Cullman, who happened upon the bisected head of a femur in a colleague's lab. "Why, that's my crane!" he is said to have exclaimed, and indeed, the pattern of struts in the bone would have looked remarkably like the pattern of girders in the heavy-duty crane Cullman had just designed for a loading dock. Further investigations of bones ranging from heels and wrists to vertebrae have revealed that struts tend to follow the lines of stress to which the bones are normally subjected. For example, most of the struts in the human heel are oriented so that they dissipate the impact associated with walking, while the orientation of the struts in the wing of a vulture counteracts the bones' tendency to bend during flapping.

Our bones develop from soft cartilage. Evidence of these cartilaginous beginnings can be seen in the soft spot in the center of a baby's skull or in the way a child tends to bounce where an adult would break—or at least hurt mightily. Most of our cartilage is gradually replaced by bone, which becomes more and more mineralized (and thus heavier) until reaching a peak in early middle age. Then, for reasons probably having to do with changing hormone levels, the rest of the body starts to extract calcium stored in the bones. (Our bodies use calcium as a signaling ion. Every time a muscle contracts, for example, huge numbers of calcium ions move through cell membranes. As we age, our bodies become less

Illustrations by Sally J. Bensusen





HOW TO BREAK A HIP With age, the meshwork of struts at the ends of bones becomes thinner and more porous. In the human hip, struts positioned to bear the weight of normal walking remain strong longer than non-load-bearing struts. Impact from another direction—during a fall, for instance—can cause sudden failure.

efficient at maintaining a constant level of calcium in the system and must mobilize it from the bones.) This natural process is especially rapid in postmenopausal women, leading in many cases to significant reductions in bone density and eventually to osteoporosis. An elderly woman with advanced osteoporosis might have just 50 percent of the bone mass she had in her early thirties.

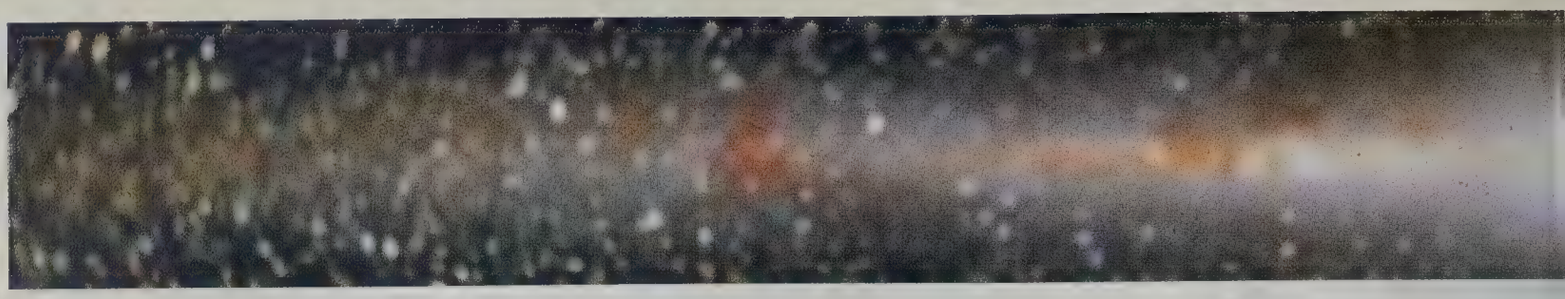
We lose trabecular bone twice as fast as cortical bone. Recently, Tony Keaveny, a bioengineer at the University of California, Berkeley, uncovered an interesting wrinkle in trabecular bone loss. It turns out that not all struts are created—or rather, lost—equally. The most durable are those positioned to withstand the loads to which a bone is most often subjected. This helps explain why a hip that is still strong enough to carry the burden of everyday movements is far less able to withstand the stress of a fall.

Once enough bone mass has been lost, however, all trabecular struts—regardless of their orientation—are prone to failure. Keaveny has pioneered an unusual method for determining just how failure happens. With a high-resolution CAT scanner, he makes a computer model—accurate down to 0.015 inch—of a section of trabecular bone. Using a supercomputer, he "pushes on the model bone until it breaks." These simulations have led him to conclude that when trabecular bone is subjected to stress from the usual directions, failure (breakage) is primarily due to crushing. On the other hand, stresses that come from other directions force the struts to bend, reducing their effectiveness.

How might these insights aid efforts to repair bones weakened by mineral loss? Keaveny points out that while replacing an entire osteoporotic bone is impractical, strengthening or augmenting its trabecular struts might be possible. In their tissue-culture facility, he and his colleagues start with a sterile block of trabecular bone—the scaffolding—which they submerge in a solution of nutrients, osteoblasts (bone-building cells), and various growth factors. For the next several weeks to months, the researchers monitor the tissue culture with CAT scans and, if all goes well, track the development of new, mineralized material. Computer simulations can test how much strength the new growth has added. This combination of engineering, tissue culture, and basic biology has raised the possibility that one day, an injection of cells and growth factors may stimulate old bones to thicken their thinning struts.

Meanwhile, research shows that exercise helps make bones stronger and denser. So, baby boomers, to keep osteoporosis at bay, take the stairs, not the elevator, and keep lifting those weights.

Adam Summers is an assistant professor of ecology and evolutionary biology at the University of California, Irvine.



Milky Way Mystery

What you see depends on how you see it.

By Richard Panek

We know what that whitish blur across the night sky is: the Milky Way. And we know what the Milky Way is: our galaxy. Now if only we knew exactly what a *galaxy* is.

As one of the most prominent features in the sky, especially on a moonless night, the Milky Way was a subject of speculation for several millennia. Ancient astronomers wondered if it was something unlike everything else up there. A giant cloud, perhaps? Only after Galileo used one of the first telescopes to resolve the seeming spill across the heavens into a "congeries of innumerable stars" did observers know for sure what it was: more of the same.

But more of the same *what*? If the Sun and planets comprised a solar system, as natural philosophers had figured out by the end of the seventeenth century (see "Celestial Events," February 2001), did all the stars in the night sky, along with our own star, the Sun, comprise a further system of their own? And if so, what would the shape of this star system be?

In 1750, when it was still difficult not to think of the "fixed stars" as lying at some uniform distance from Earth, English philosopher Thomas Wright suggested that the Milky Way might be merely an optical effect. What if, he speculated, the seemingly dense concentration of stars was actually a standard distribution that only *looked* dense because we happened to be seeing this section of sky edge-on? Five years later, German philosopher Immanuel Kant elaborated on this possibility, suggesting that the overall stellar system might be disk shaped. But not until British astronomer William Herschel began plumbing the depths of the stars in the late eighteenth century, at long last endowing the night sky with a true third dimension, did astronomy arrive at a modern model of what this system might resemble: a giant cluster roughly in the shape of a convex lens.

When we look at the Milky Way, then, what we're seeing is the disk of our spiral galaxy. The word "galaxy" derives from the Greek *gala* (milk), and the designation "Milky Way," in fact, can refer either to that visible stretch of stars or to the overall stellar system, in much the same way that "New York" can mean either the city or the state.

As is the case with most astronomical phenomena, galaxies reveal entirely different aspects when we examine them in wavelengths of light that our eyes can't see—infrared or X rays, for instance. By observing infrared radiation from the central region of the Milky Way, astronomers can see through the dust and gas that obscures our visible-light view of the millions of stars in our spiral galaxy's bulge. The contrast observed in X rays is even more extreme. As the Space Telescope Science Institute's Megan Donahue said at a recent astronomy conference, referring to a stunning photograph of a large group of galaxies, "If we had X-ray telescopes at the turn of the century, we wouldn't call these 'galaxy clusters' but 'gas clusters.' The luminous matter"—hundreds of billions of stars—"is just the froth on the gas."

If the stars are the froth on the gas, the gas, in turn, is the froth on . . . well, astronomers aren't sure what. They've known since the 1970s (and some suspected as far back as the 1930s) that the gravitational interactions of galaxies indicate the presence of something they can't detect in any band of light, from radio waves all the way to gamma radiation. "Dark matter," they decided to call it. According to most estimates, this dark matter comprises at least 90 percent of the mass of most galaxies, including our own.

But not only don't astronomers know what 90 percent of the mass of a galaxy such as our own is; they're not sure where it is, either. Does dark matter permeate the Milky Way? Probably not, since astronomers don't find evidence for it in the gravitational interactions of individual stars. Instead, they've posited, dark matter forms a halo around the galaxy, but whether it's spherical or oblate, and how far it extends—or if it even exists—remain frustratingly persistent mysteries.

The best time to see the Milky Way's galactic bulge is when the sky is very dark; around the time of the new Moon is a good bet for that. In September, the sky is darkest on the

The Milky Way's galactic bulge (based on false-color satellite data)

16th. Weather permitting, a whitish blur will be visible between the northeastern and southwestern horizons in the first hours after nightfall. As for the complete Milky Way Galaxy, at least 90 percent of it won't be visible. But then, it never is. What's always been true of the night sky still holds, only now more than ever: it's dark up there.

Richard Panek's latest book, The Invisible Century: Einstein, Freud, and Our Search for Hidden Universes, *will be published next year by Viking.*

THE SKY IN SEPTEMBER

By Joe Rao

Mercury is visible—but just barely—along the western horizon. Look for it during the first half of September only 3° above the horizon, as seen about half an hour after sunset from midnorthern latitudes. After reaching greatest elongation from the Sun on the 18th, Mercury drops from sight.

Venus, the morning "star," settles lower and lower in the east as the weeks go by, but even by month's end it's still visible for two hours before sunrise. On the morning of September 3, the planet blazes near the southern fringe of M44, the Beehive Cluster in the constellation Cancer. The big conjunction for Venus this month is with the first-magnitude star Regulus, or Alpha Leonis, in the constellation Leo. On the morning of the 15th, a very thin crescent Moon forms a striking isosceles triangle with Venus and Regulus; the bluish white star appears 5° distant from both the Moon and Venus, which appear 3° apart. On the mornings of September 20 and 21, Venus and Regulus appear closest, with the planet passing 0.7° above Regulus on the 20th and 0.8° to its left on the 21st (Venus will be 132 times brighter than the star). By the 25th, Regulus appears to pull up and away from Venus.

Mars, positioned near the top of the Teapot in the constellation Sagittarius, loiters in the south-southwestern sky at dusk throughout September. At the start of the month it sets at about 12:30 A.M. local time, and by the end, about forty-five minutes earlier. As the planet recedes from Earth, it fades from magnitude -0.9 on September 1 to -0.4 by the 30th. Although still relatively bright, Mars shines with one-sixth the luster of its dazzling mid-June showing. The first-quarter Moon passes just above it on the evening of September 24; on the 30th, Mars in turn passes half a degree north of Nunki, a magnitude +2.1 bluish white star in the Teapot's handle.

Jupiter, in the constellation Gemini, rises at about 1:30 A.M. local time in early September and at about midnight by the end of the month. The giant planet shines brightly, low in the east, its four moons visible through even a modest telescope. A fat crescent Moon passes just north of Jupiter on the morning of September 12. From parts of northwestern Canada and Alaska, the Moon will actually occult (hide) Jupiter.

Saturn rises in the east-northeast within four and a half hours after sunset on September 1 and an hour earlier by the 30th. By dawn, it can be found high in the south, well above and to the right of Jupiter. All month, this zero-magnitude planet remains about 6° northeast of the first-magnitude star Aldebaran. On the morning of the 10th, the last-quarter Moon occults Saturn—between 1:00 and 2:00 A.M. local time in Hawaii; before sunrise on most of the U.S. West Coast (narrowly missing Seattle, however); and during the day farther east.

The Moon is full on September 2 at 5:43 P.M. and is the most distant full Moon of 2001, having arrived at apogee the previous night. Last quarter is on the 10th at 2:59 P.M. The new Moon falls on September 17 at 6:27 A.M, and first quarter is on the 24th at 5:31 A.M.

The autumnal equinox occurs at 7:04 P.M. on September 22, when the Sun, appearing to travel along the ecliptic, crosses the equator into the Southern Hemisphere. This marks the beginning of autumn in the Northern Hemisphere and spring in the Southern Hemisphere.

Unless otherwise noted, all times are given in Eastern Daylight Time.

REVIEW

MARC RIBOUD; MAGNUM PHOTO, INC.

Delusions and Degradation

How Mao Zedong's grandiose and coercive policies wrecked China's environment

By Vaclav Smil

Exactly twenty years ago, I began writing an appraisal of China's environment. The project became possible as the country abandoned the worst Maoist orthodoxies and turned, under Deng Xiaoping's leadership, to economic and social reforms. Statistics began appearing regularly again in 1978; old scientific journals were restarted and many new ones launched. Journalistic accounts boldly probed topics whose discussion had been either strictly forbidden or dishonestly couched in Maoist clichés during the long and painful reign of the Great Helmsman. Published in 1983, my book *The Bad Earth: Environmental Degradation in China* was met not only with a great deal of attention but also with disbelief, stemming from the persistence of a naive Western image of China as a civilization living in harmony with its environment, or perhaps from some American and European intellectuals' residual infatuation with Maoism (or from a combination of the two). Some readers were unwilling to accept the fact that the country's environmental problems were widespread, acute, and intractable.

Mao's War Against Nature: Politics and the Environment in Revolutionary China, *by Judith Shapiro (Cambridge University Press, 2001; $18.95)*

Since then, more than a dozen English-language books have detailed the worrisome state of China's environment. Western periodicals and TV programs have repeatedly reported on the consequences of the pollution and ecosystemic degradation that affect not only the country's population and economy but also the so-called global commons. Informed students of the world's environment are now aware of China's enormous problems (China is the world's top producer of airborne sulfur dioxide and particulate matter from coal combustion, and less than one-fifth of all the country's wastewater is treated before discharge). Environmentalists are alarmed by prospects of the country's continuing desertification, massive soil erosion, and loss of mature forests, not to mention the consequences of damming the Yangtze River for the planet's largest hydroelectric project. (Surprisingly, however, greenhouse gas emissions have been falling in China, due to carbon absorption by forests planted in the 1970s.)

Most acute are the widespread shortages of water in the semiarid-to-arid region of northern China that includes Beijing and supports two-fifths of the nation's industrial and agricultural production (while relying on less than one-tenth of the country's total runoff). These shortages, intensified by the cessation of the Huang He's (Yellow River's) flow for up to five months a year during the past decade, are supposed to be solved by a vast interbasin water transfer from the Yangtze, another megaproject with worrisome environmental consequences.

In her new book about the history of China's environmental degradation during the Mao era (1949–76), Judith Shapiro—a professor of environmental politics at American University in Washington, D.C., and coauthor, with Liang Heng, of several books on China's Cultural Revolution and its aftermath—is no longer facing naive readers. But critics who question her personification of the past in the book's title—*Mao's War Against Nature*—would be wrong. Assigning the guilt to Mao is historically correct. During his emperorlike reign, decisions were not the result of careful, collective deliberations of the Communist Party leadership; rather, they were a direct reflection of the chairman's ignorance, biases, and disdain for the suffering of others. For

more than a quarter century, his decisions affected every aspect of life in China and were responsible for not only massive environmental degradation but also the political persecution and death of millions. The most monstrous consequence, however, was the worst famine in world history, with a death toll of 30 million people between 1959 and 1961.

Shapiro's historical account of these devastating decades follows, sensibly, a topical rather than chronological sequence. Her earlier publications on China deal with the country's modern history, politics, and intellectual life (her field of expertise), and she uses these filters to look at the enormous environmental changes experienced by the country during the third quarter of the twentieth century. Shapiro argues her case by combining published information (from Mao's writings, newspaper and magazine accounts, biographies, and memoirs) with vivid personal descriptions and the recollections of numerous people she interviewed while teaching and traveling in China. This combination works to illustrate the madness of Maoist policies—the irrational designs that caused such suffering and such destruction of nature.

The travails of two notable Chinese intellectuals who dared disagree with Mao, and who paid a high price for their boldness, are discussed first. Economist and demographer Ma Yinchu called for population control at a time when Mao was extolling unlimited population growth. And China's leading hydroengineer, Huang Wanli, questioned the building of the Soviet-designed Sanmenxia, the first dam on the Huang He, whose reservoir began rapidly silting soon after the project's completion. Both men were lucky. Although their professional careers ended in 1958, they survived.

The book then turns to the Great Leap Forward, meant to elevate China to a new economic level in a matter of years. But the Maoist regime's criminally naive schemes for instant industri-

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alization—involving massive deforestation to produce charcoal for inefficient, primitive iron furnaces—brought on the neglect of farming as well as the aforementioned horrific famine.

Almost as soon as the country recovered, Mao plunged it into a new round of social convulsions in 1966, known—most inappropriately—as the Cultural Revolution. "Learning From Dazhai" was a key slogan of that period, imploring people to copy the achievements (vastly exaggerated or even entirely fictitious) of a formerly impoverished village. Widespread destruction of lakes and wetlands for the purpose of creating new cropland was one of the most unfortunate aspects of Mao's campaigns, and a detailed description of the disastrous results takes up the book's third chapter. The fourth deals with preparations for war with the USSR and the forcible relocation of industries (and urban youth) to the country's interior during the late 1960s and early 1970s. The environmental consequences of these programs included the destruction of large areas of tropical forest in southern China to make way for rubber plantations and the conversion of grasslands in the north into erosion-prone cropland.

"Maoist coercive, state-sponsored experiments for social improvement came at a dangerously high price," Shapiro writes. "The issues raised by the Mao years thus remain deeply relevant." Both for readers interested in China's past and for those concerned about its future, the story Shapiro tells is a valuable account of Mao's regime—one of the last century's most tragic episodes.

Vaclav Smil teaches in the University of Manitoba's geography department. His most recent books, both published by MIT Press, are Feeding the World: A Challenge for the Twenty-First Century *(2000) and* Enriching the Earth: Fritz Haber, Carl Bosch, and the Transformation of World Food Production *(2001).*

nature.net

Becoming Human

By Robert Anderson

Many people dismiss evolution on the grounds that it is only a theory. Our president is of the opinion that "the jury is still out" on it, according to a *New York Times* article last year.

But consider what "theory" means, as the word is properly used in the sciences. Physicist Alan H. Cromer, in his 1993 book *Uncommon Sense: The Heretical Nature of Science,* reminds us that a theory is not to be confused with "an idea tentatively held for the purposes of argument—that we call a hypothesis. Rather, a theory is a set of logically consistent abstract principles that explain a body of concrete facts." Evolution is firmly based on just such a logical structure and is therefore every bit as certain as the existence of atoms.

On the Internet, Becoming Human (www.becominghuman.org) makes a nice introduction to the theory of human evolution and to the rapidly growing number of hominid fossils that support it. The centerpiece of the site, produced by the Institute of Human Origins at Arizona State University, is an interactive documentary narrated by Donald Johanson, the discoverer of the "Lucy" hominid remains. Although designed for those with a high-speed connection, the site can be viewed in bits and pieces with slower access.

Becoming Human shows the Internet's ability to update a site as new information surfaces. The "News and Views" section, for instance, recently posted several links to sites covering the discovery of a new species (the 3.5-million-year-old *Kenyanthropus platyops)* that challenges Lucy's pivotal position in our lineage.

Robert Anderson is a freelance science writer living in Los Angeles.

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BOOKSHELF

Wild Nights: Nature Returns to the City, *by Anne Matthews (North Point Press, 2001; $22)*
Coyotes, peregrine falcons, wild turkeys, and other wildlife are now sighted in and around New York City—an amazing resurgence in "a profoundly unnatural landscape; a competitive maze; a wonder of money and art."

Holding Back the Sea: The Struggle for America's Natural Legacy on the Gulf Coast, *by Christopher Hallowell (HarperCollins, 2001; $26)*
In the Mississippi River delta—an area with more than 3 million acres of marsh and swamp—massive erosion, rising sea levels, introduced species, and other agents are destroying about twenty-five square miles of wetland a year and threatening the fish harvest, gas and oil reserves, the local residents, and even New Orleans itself.

Blue Nile: Ethiopia's River of Magic and Mystery, *by Virginia Morell (National Geographic/Adventure Books, 2001; $26)*
In her account of rafting 560 miles down the Abay Wenz ("great river")—from Lake Tana in Ethiopia to the Sudanese border—Morell interweaves the day-to-day drama of an expedition with a history of the river and portraits of its peoples.

Barren Lands: An Epic Search for Diamonds in the North American Arctic, *by Kevin Krajick (Holt, 2001; $24.95)*
In 1991, in Canada's remote Northwest Territories, a small-time prospector discovered eighty-one tiny diamonds in a crater lake, precipitating "one of the greatest mining rushes in history."

The Mummy Congress: Science, Obsession, and the Everlasting Dead, *by Heather Pringle (Hyperion, 2001; $23.95)*
The Third World Congress on Mummy Studies, held in Chile in 1998, gave journalist Pringle the opportunity to observe this quirky discipline and to explore the "intimate relationship between the living and the everlasting dead."

Making Babies: The Science of Pregnancy, *by David Bainbridge (Harvard University Press, 2001; $26)*
Reproductive biologist Bainbridge investigates the coexistence of mother and fetus during the forty weeks of gestation and concludes that human pregnancy is "a triumph of the natural world, but it can have strange unforeseen effects," from the mother's susceptibility to disease to the outcome of a male child's sexual orientation.

The Parrot Who Owns Me: The Story of a Relationship, *by Joanna Burger (Villard Books, 2001; $23.95)*
A red-lored Amazon rules the roost at an ornithologist's New Jersey home. In recounting her stormy but loving relationship with Tiko (the bird is forty-six years old by the end of the book and could live to sixty or seventy), Burger provides information about the behavior of birds of every feather.

Walking on Eggs: The Astonishing Discovery of Thousands of Dinosaur Eggs in the Badlands of Patagonia, *by Luis M. Chiappe and Lowell Dingus (Scribner, 2001; $25)*
Four years ago, a paleontological team led by Chiappe and Dingus discovered a dinosaur nesting ground in Argentina, covering more than a square mile and littered with vast numbers of egg fragments and intact five-inch eggs. The authors piece together the events that prevented these eggs from hatching 70 million years ago.

The Southwest Inside Out: An Illustrated Guide to the Land and Its History, *by Thomas Wiewandt and Maureen Wilks (Wild Horizons, 2001; $24.95)*
Abundant photographs, historical tidbits, fascinating facts, and amusing anecdotes complement clear explanations of the natural features of North America's desert and canyon country: its dunes, rocks, cliffs, and water.

The books mentioned are usually available in the Museum Shop, (212) 769-5150, or via the Museum's Web site, www.amnh.org.

GWENDOLEN CATES

Indian Country, *photographs by Gwendolen Cates (Grove/Atlantic, 2001; $44.95)*

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THE NATURAL MOMENT

Dry Cleaning

Near the village of Yamato, Japan, in late spring, a paper wasp queen *(Polistes chinensis)* tends a nest she has built on a dead stalk of goldenrod. A potential queen begins her colony by searching out a patch of the species' favorite flowers, where she mates with a suitable male. Next she chooses a nest site and constructs about twenty hexagonal cells from a durable papier-mâché of chewed wood fibers mixed with saliva. After completing each cell, the queen deposits an egg in it before starting the next one. When the larvae hatch, she will feed them chewed-up caterpillars until they are ready to pupate. At that time, each larva wraps itself in a cocoon, plugs its chamber with silk, and becomes quiescent.

For the next three or four months, while the youngsters mature, the foundress cleans the nest regularly and helps keep it cool by fanning her wings. All the cell openings are angled downward, thus preventing rainwater from collecting in them and drowning the larvae. Any water that adheres after a rain must be swallowed by the queen and then regurgitated, drop by drop, over the side—an action captured in this photograph. In autumn, the larvae emerge as adult workers and begin enlarging the colony.

—*Richard Milner*

Photograph by **Hiroshi Ogawa**

ENDPAPER

Garbage Out, Garbage In

By Alan S. Kesselheim

It is my first morning of a week in paradise—the Sian Ka'an Biosphere Reserve on the east coast of Mexico's Yucatán peninsula, where a vast living coral reef bumps right up against the shore. I am here to teach a writing workshop. Before me stretches the electric-blue Caribbean. Beneath my feet, the sand of pulverized coral has the pillowy, soft texture of white flour. It takes me a while to notice the garbage.

Plastic bottles, milk cartons, sandals, strands of rope, disposable diapers, shopping bags, six-pack holders, sunglass frames, broken Styrofoam coolers, baseball caps, plastic GIs. They bob in the surf alongside incoming coconuts, mingle with the seaweed at the high-water line, flutter in the shrubs at the back of the beach. Not what I expected to see at a UNESCO World Heritage Site.

On the beach in the Sian Ka'an Biosphere Reserve, Mexico

STEVEN R. HAGE

Farther north along the coast, garbage is not allowed. From Cancún to Tulum, along a sixty-mile strip of vacation real estate known as the Mayan Riviera, much of the beach is not only patrolled for litter each day but also manicured every morning by workers wielding rakes. In some places, the sand is refreshed periodically with truckloads brought in from elsewhere: beaches to go.

But in the protected reserve, the natural state is upheld, including our prolific, enduring detritus.

"It is literally the garbage of the world," my host, Anna Woods, tells me. A part-time resident, she runs a series of artists workshops in the reserve. Woods has found medical waste from New York City hospitals washed up, the addresses still intact on the containers. In order to reach this coast, such refuse must first be swept north and east by the Gulf Stream to Europe, then south toward Africa and west across the Atlantic—a loop of roughly 10,000 miles. "Some of it might have gone around twice," says Woods.

She shrugs when I ask if I could pick up some of the trash. "It's a five-hour round trip on very bad roads to dispose of it at the dump outside of Tulum. Who knows how it's taken care of there."

Over the days I learn to filter out the litter, at least most of the time. I focus on the bleached shells, the hunks of intricately patterned coral, the hermit crabs dragging their homes through the sand like martyrs on a pilgrimage.

Halfway through my week, as I walk down the beach, I meet Cruz, a skinny eleven-year-old boy from a nearby *rancho*. In a pouch made with his faded T-shirt, he carries his morning's treasure—a stash of plastic and Styrofoam knickknacks thrown up by the sea. There is not a single shell or rock or lump of coral in the mix.

Cruz has never been to a Wal-Mart. But if he is patient and alert enough, almost anything can come to him. He arranges and rearranges his coastal trove in the yard outside his house the same way my kids play with their Lego sets and plastic barn animals in our basement. His model ranches consist of assorted boxes and cartons, with twine fences, milk-carton horse stalls, and a syringe for a tiny silo. An extensive system of roads conveys cars and trucks. A surprisingly large assortment of suitable farm animals inhabit the spread, although the rancher may be a garish action figure or space alien, and his wife the nude upper half of a Barbie doll.

My last morning at the reserve, I walk the flour-sand shoreline one final time, searching for pretty shells or convoluted knobs of coral to carry home to my kids. The breeze is blowing onshore; the waves break across the reef.

I notice that I am unconsciously surveying the beach the way Cruz does, without judgment, watchful for some glimmer of surprise. I am alive to the possibility that I just might find some stunning piece of the world's refuse to cart back, a treasure in honor of Cruz.

Freelance writer Alan S. Kesselheim is a columnist for Big Sky Journal *and a contributing editor for* Canoe & Kayak. *His latest book is* The Wilderness Paddler's Handbook *(McGraw-Hill, 2001).*

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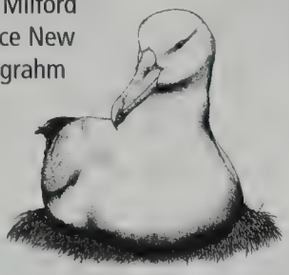

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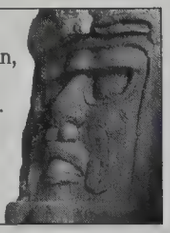

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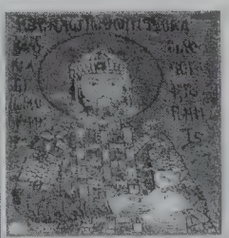

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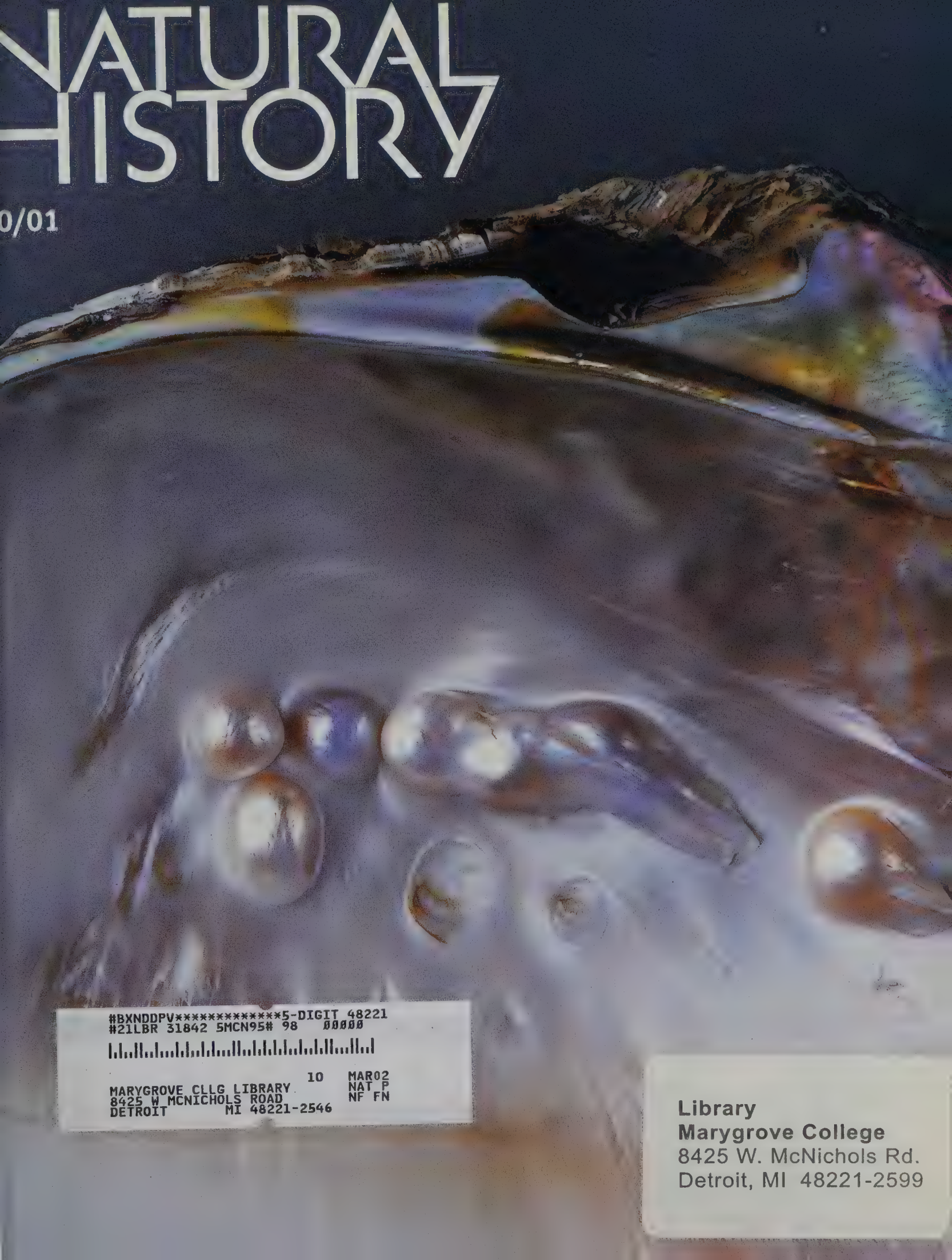

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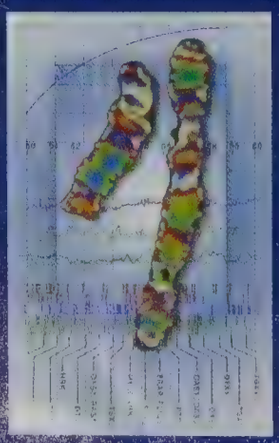

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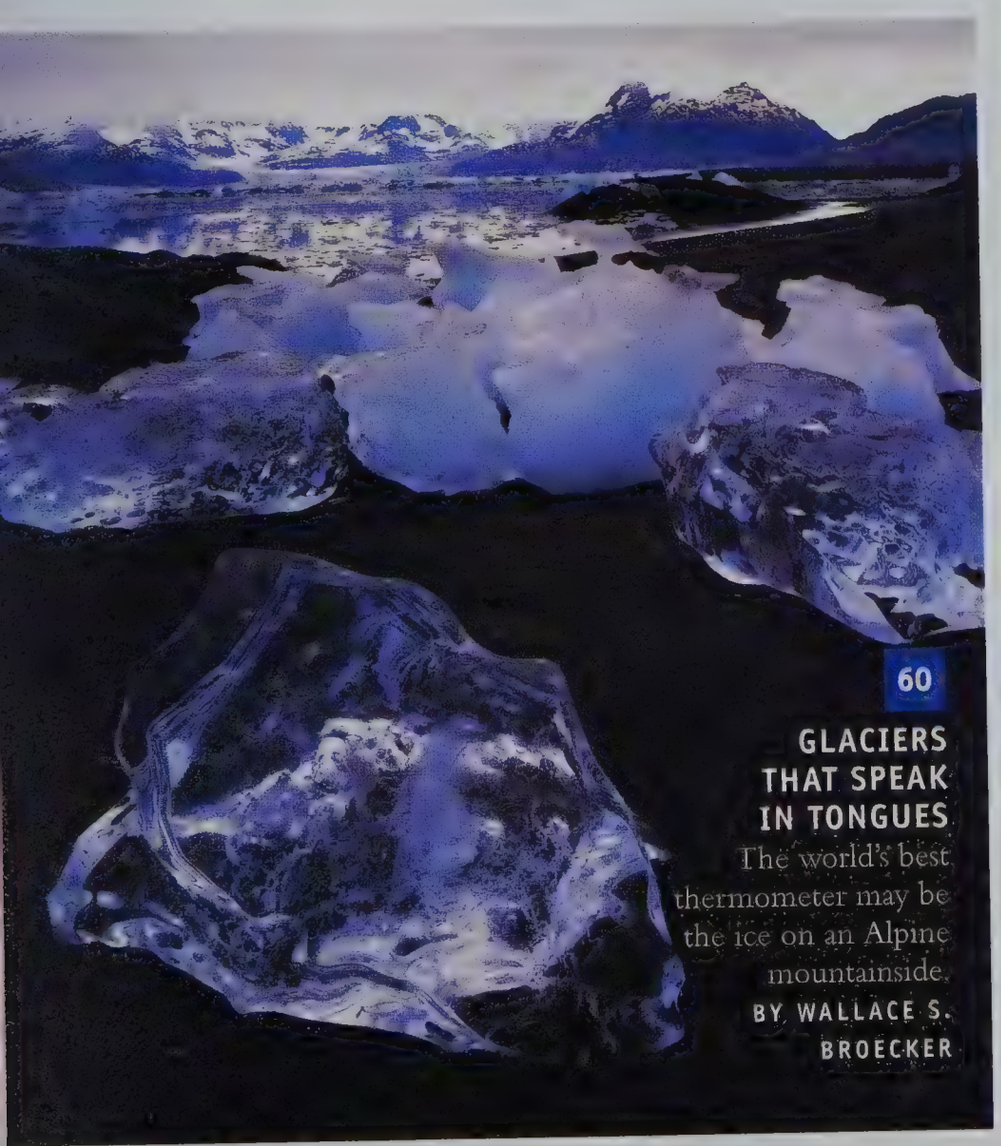

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The world's best thermometer may be the ice on an Alpine mountainside.

BY WALLACE S. BROECKER

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SHAPE SHIFTERS

As a general rule, lizards run around on all fours. Yet legless species have evolved again and again.

BY JOHN J. WIENS

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SEA HUNTERS OF LAMALERA

Their boats are sacred and, they believe, immortal.

STORY AND PHOTOGRAPHS BY FRED BRUEMMER

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A triangleshell pearl mussel. When Columbus sailed to the New World, pearls were on the top of his patrons' wish list.

STORY BEGINS ON PAGE 12

PHOTOGRAPH BY DENIS FINNIN; AMNH

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ENGINEERING THE APPLE

If Mendel had started out with fruit trees instead of pea plants, genetics might have been set back a hundred years.

BY SUE HUBBELL

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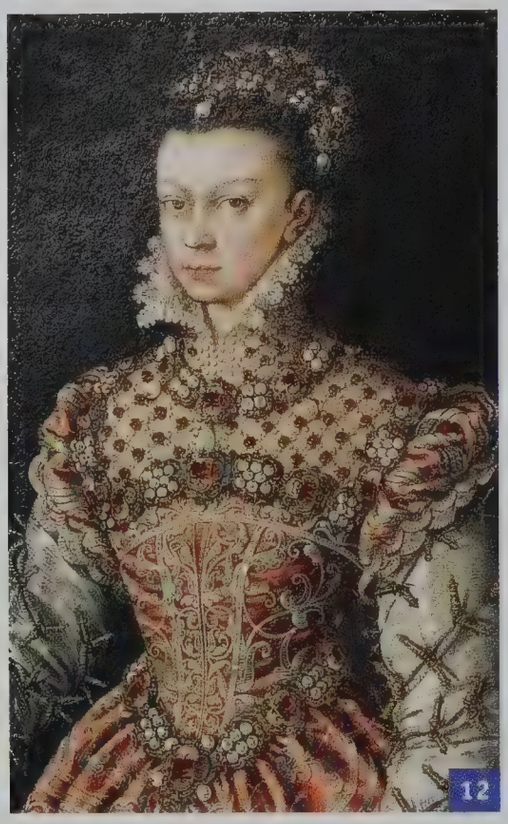

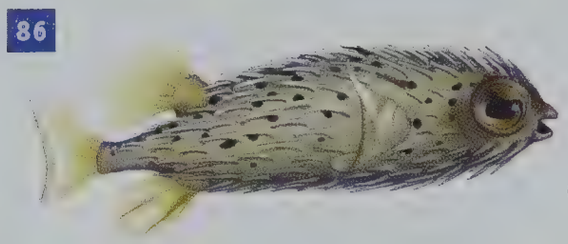

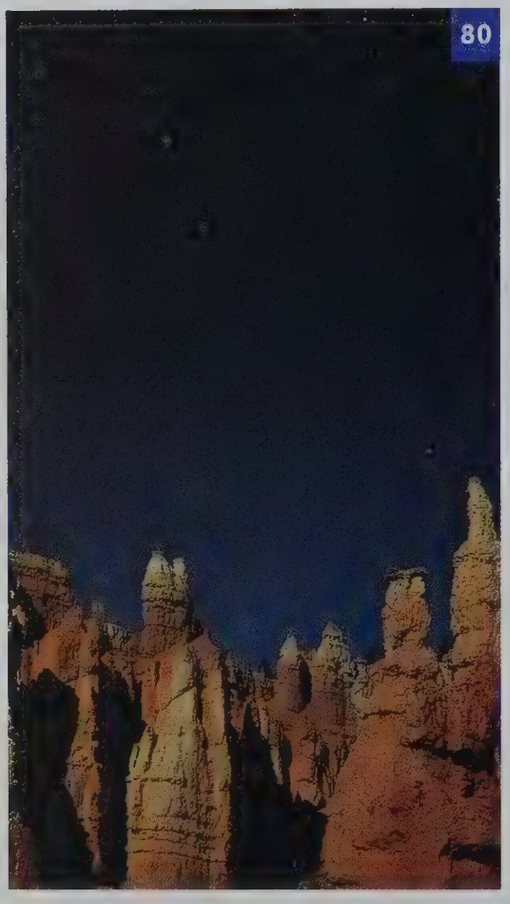

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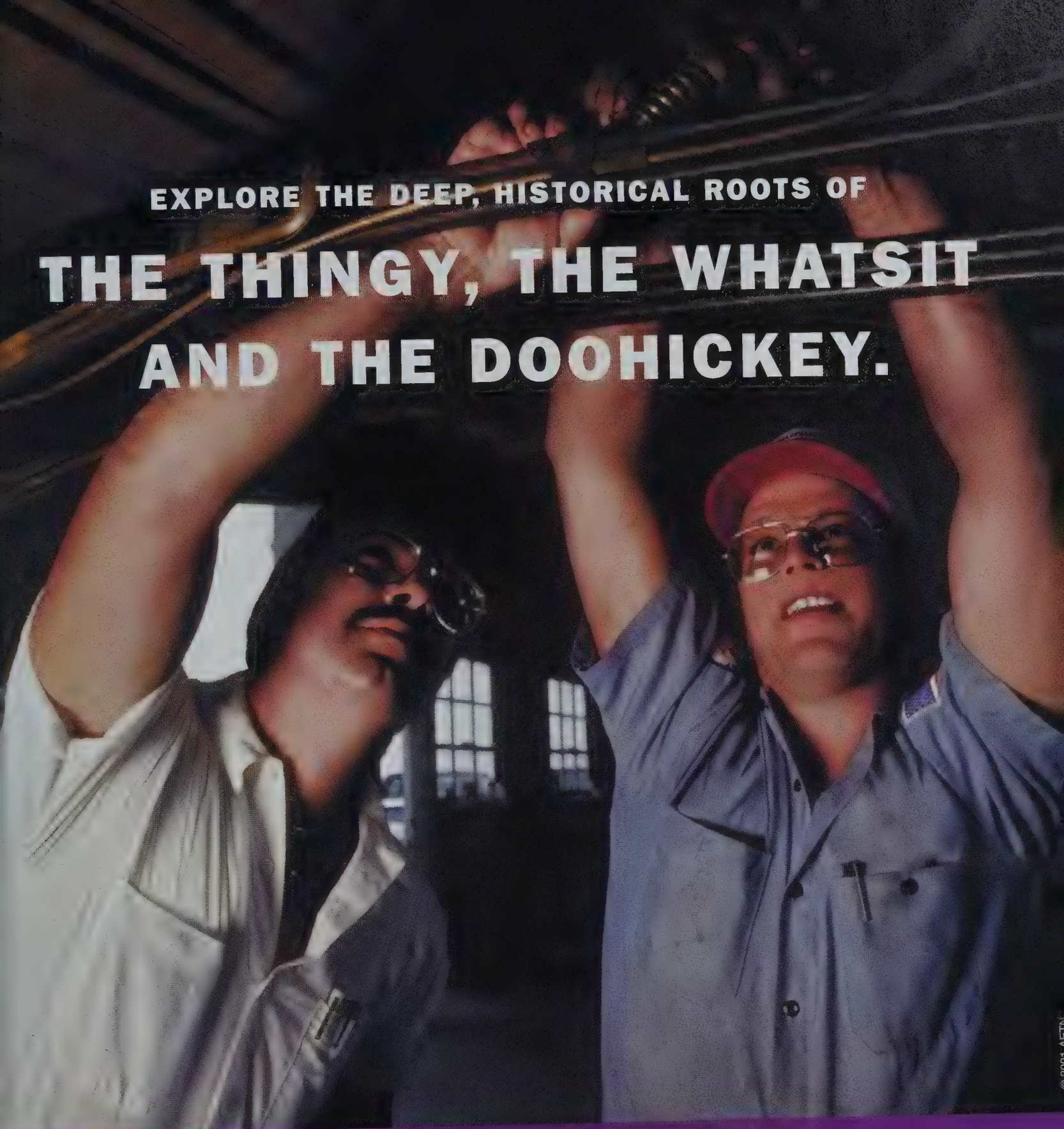

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UP FRONT

Time Travelers

"What seest thou else in the dark backward and abysm of time?"
—William Shakespeare, *The Tempest*

As a mid-twentieth-century schoolchild, I thought of the First World War as a distant event. I placed all the historical figures of previous centuries in more or less the same category, the remote past, which included everyone from Moses to Abraham Lincoln. My perceptions changed as I aged, of course. At my fiftieth birthday, I realized that the entire history of the United States had occurred within a span that amounted to little more than four of my lifetimes. The nineteenth century was a temporal stone's throw from my parents' childhood and, therefore, from my own life. From the vantage point of my middle age, certainly Abraham Lincoln and maybe even Louis XIV had become my contemporaries.

Working at *Natural History* has altered my perspective far more radically. Scientists' tales of fossils and shifting tectonic plates have taught me a new kind of history. Bacteria were the ancients, dinosaurs a late development, mastodons born yesterday. Lincoln's birthplace in Kentucky once lay under a shallow tropical sea filled with brachiopods and trilobites; the Des Moines area emerged quite recently from beneath a glacier.

MUZEUM NARODOWE WE WROCŁAWIU, WROCŁAW

Switzerland's Grindelwald Glacier, 1794

More than other scientists, natural historians—the geologists, paleontologists, evolutionary biologists, and others who write for these pages—are time travelers. And more than other people, they are aware that present reality represents a mere moment, a freeze-frame in a long drama of upheaval and transformation. This month, in "Glaciers That Speak in Tongues" (page 60), geochemist Wallace Broecker addresses the question of humanity's contribution to global warming. Scientists cannot yet identify this contribution with precision, he explains, because to do so requires that they first establish the dynamics and natural baseline of Earth's recent temperature variations. By "recent," Broecker means the Holocene Epoch—just the past 11,000 years or so. Lately, he tells us, his colleagues have been finding a record of these climate patterns in surprisingly simple things—reddish grains of sand, bits of wood washed out from under mountain ice. Janus-like visionaries, these climatologists look backward to help us predict the future.—*Ellen Goldensohn*

NATURAL HISTORY
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LETTERS

Osage (Orange) Can You See?

I was surprised to see the picture caption in Connie Barlow's "Ghost Stories From the Ice Age" (9/01) about Osage orange trees being confined to a few river valleys in eastern Texas. The tree is common to this part of the Ozarks and has been at least since white settlers arrived. The wood was supposed to have been used by Native Americans for their bows.
T. B. Clark
Berryville, Arkansas

BILL BEATTY

Osage orange tree

A tree and fruit that looked just like your picture of Osage orange were certainly to be found smelling up Milledgeville, Georgia, where I grew up. Maybe you should check there for Pleistocene horses, too.
James F. Minter
New York, New York

The Osage orange, called hedge apple in Missouri, is found all over the Ozarks of southern Missouri. There is a belief that putting the fruits in your kitchen will keep roaches away. I tried it once. It did not work.
H. M. White
via e-mail

Connie Barlow writes that the Osage orange tree is rare. However, many rows of old Osage oranges can be found in New Jersey. This species, characterized by thorns and dense growth, was at one time widely planted by farmers in the East to form impenetrable living fences, similar to Old World hawthorn hedgerows. As the trees grew, farmers pruned them to force the plants into hedge forms. After the farms were abandoned, the hedges resumed their natural, treelike growth.
Norman Fine
Sewell, New Jersey

CONNIE BARLOW REPLIES: The letter from Norman Fine contains the seed of the answer to all those who protested that the geographic range of Osage orange is far wider than I stated in the article. *After* European settlers arrived, Osage orange became exceedingly popular as a "living fence," and its range was expanded by human plantings until barbed wire became cheaply available.

This was especially so in the prairies and plains, where a scarcity of trees made wooden fencing impractical. Botanists have surmised that the post-glacial native range of Osage orange was probably restricted to the Red River region, where Arkansas, Texas, and Oklahoma meet. A year ago, an archaeologist exploring the Indian trade in Osage orange for bow wood proposed that the native range may have been even more restricted—to just a few tributaries of the Red River in eastern Texas. (See Frank F. Schambach, "Spiroan Traders, the Sanders Site, and the Plains Interaction Sphere," *Plains Anthropologist* 45:171, 2000. Or see my book *The Ghosts of Evolution* [Basic Books, 2001] for the full story.)

Hawthorn (genus *Crataegus*) is native to both the Old and the New World, with the eastern United States boasting the richest diversity of species.

Buffalo Grass

"Ghost Stories From the Ice Age" fascinated me. The flora of this country also includes ghosts from the nineteenth century: plants that coevolved with the American bison. Among these are three-awned grasses of the genus *Aristida,* with long bristles, or awns (well designed for penetrating the coat of a bison—or one's wool socks), and running buffalo clover, *Trifolium stoloniferum.* After the buffalo disappeared from the midwestern landscape, the clover itself became very rare and was once even thought to be extinct.
Bill Shepherd
Little Rock, Arkansas

Color Question

In "The Proof Is in the Plumage" (7/01–8/01), on a feathered dromaeosaur from China, one of Mick Ellison's close-up photographs on page 61 reveals some fairly conspicuous red paint applied above the dromaeosaur's humerus. Close inspection also shows black paint in two photographs. Both the red and the black paint have been cleaned up in the large photograph on page 60. It seems unlikely that the bright scarlet color is simply an accidental property. Was the fossil acquired with this curious red paint upon it?
Jordan Moar
Waterloo, Ontario

PHOTOGRAPHER MICK ELLISON REPLIES: Farmers in China's Liaoning region have been collecting fossils in the area for decades. Specimens are rarely found in one unbroken piece, and the process of reconstituting them is akin to completing a jigsaw puzzle. The excavators often highlight parts of the fossil with grease pencils or other markers, presumably to indicate how one piece might fit with another. For the cover of the issue and the photograph on page 60, the dromaeosaur's "tailoring" marks were digitally removed.

Natural History's e-mail address is nhmag@amnh.org.

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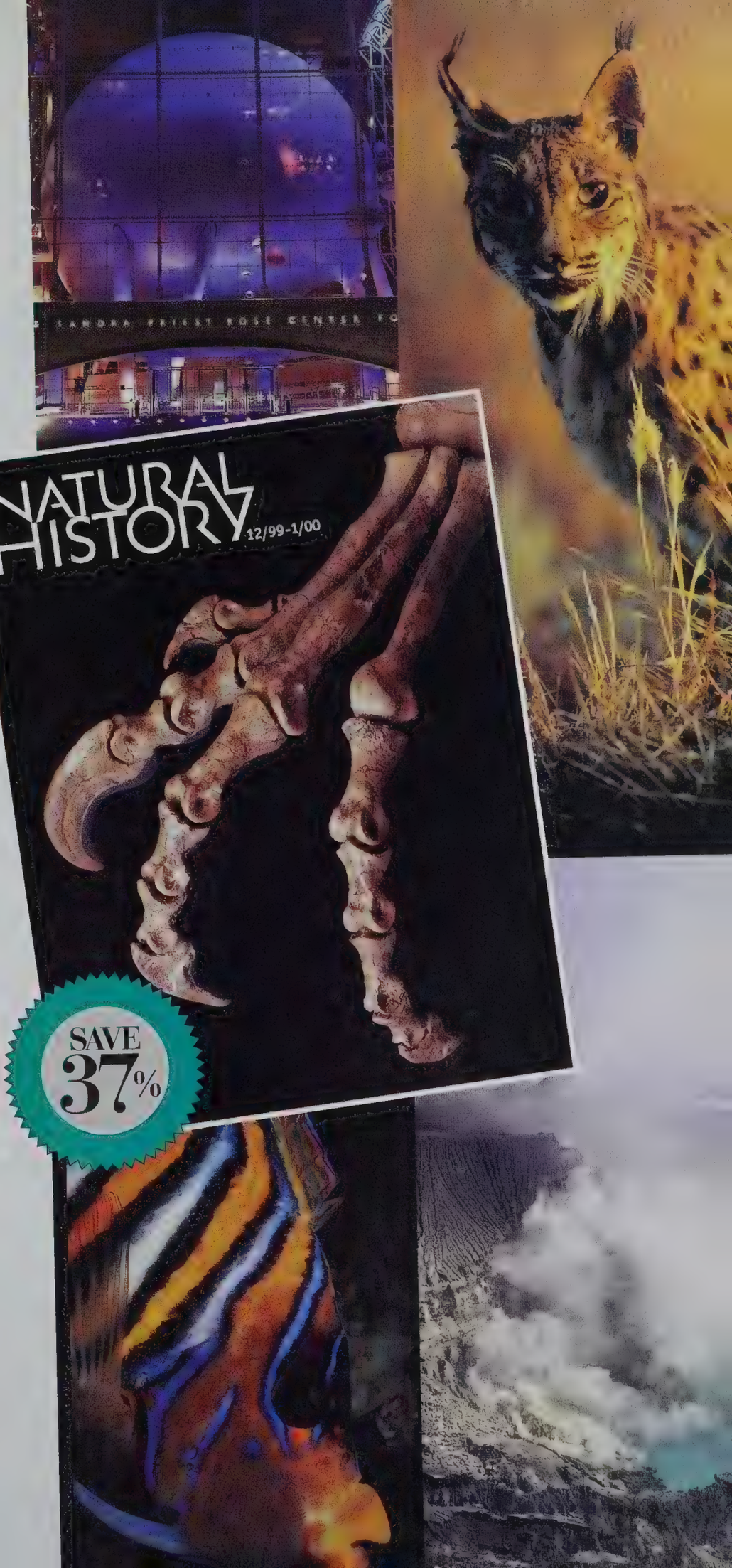

CONTRIBUTORS

Sue Hubbell ("Engineering the Apple," page 44) did not plan to write another book after her last one (*Waiting for Aphrodite: Journeys Into the Time Before Bones,* Houghton Mifflin, 1999). But as she worked in her woodlot and built stone walkways around her Maine house, she began to reflect on her "proclivity for rearranging bits of the world." This realization led her to investigate "a few animals and plants whose genetic identity we have tinkered with to varying degrees"—dogs, corn, silkworms, lions, cats, rats, and apples. Unraveling the history we have shared with these organisms, as well as the unintended consequences of our experiments with them, became another book, *Shrinking the Cat: Genetic Engineering Before We Knew About Genes,* published this month by Houghton Mifflin.

Fred Bruemmer ("Sea Hunters of Lamalera," page 54) has been a writer and photographer since 1952 and a contributor to *Natural History* for almost as long. Over the years, he has been drawn back again and again to the Arctic and has written several books on aspects of Arctic life. Bruemmer, who lives in Montreal, has spent considerable time among subsistence sea hunters, including walrus hunters in Little Diomede Island in the Bering Strait, narwhal hunters in Greenland, and sperm whale hunters in the Azores. Lamalera, on the Indonesian island of Lembata, was a natural destination for him, he says, because of "the boats, the hunt, and the animistic link between hunter and prey."

A recent visit to the Alps provided **Wallace S. Broecker** ("Glaciers That Speak in Tongues," page 60) with a firsthand glimpse of new evidence of past climate changes. Guided by Swiss glaciologists, he and the others in the visiting field team found fifty samples of ancient peat and wood that had washed out from beneath the glacial ice—signs that vegetation once grew in areas now frozen over. The Newberry Professor of Earth and Environmental Sciences at Columbia University's Lamont-Doherty Earth Observatory, Broecker is the author of a text on the evolution of Earth, *How to Build a Habitable Planet* (Columbia University Press, 1998). Among his previous articles for *Natural History* is "Global Warming on Trial" (April 1992).

As a child, **John J. Wiens** ("Shape Shifters," page 70) kept dozens of pet reptiles and amphibians in his bedroom. When the number got out of hand, he packed up and moved into a different room, bequeathing the bedroom to the animals. Now, as an associate curator at the Carnegie Museum of Natural History in Pittsburgh, he has an entire three-story building full of herpetological specimens at his disposal. For many years, Wiens has been fascinated by the evolution and diversity of lizards and snakes, and he says that studying how one turns into the other is a perfect way to combine his interest in both groups. He plans to extend his studies of the evolution of body form to salamanders and to skinks, the group of lizards in which a snakelike body plan has evolved most frequently. Wiens's other research interests include reproductive strategies in tree frogs and the evolution of herbivory in South American lizards.

Theo Allofs ("The Natural Moment," page 88), a resident of Canada's Yukon Territory, has traveled the world photographing wildlife. During late December 1999 and January 2000, he positioned himself in the midst of a large colony of flying foxes not far from Brisbane, Australia, where he took this month's photograph of a little red flying fox. Despite his concealment in a blind, Allofs reports, the fruit-eating bats knew he was there and were not upset by his presence. But when they returned from foraging to roost above him in the trees, he was "bombarded by hundreds of 'fruitcakes.'" Whenever Allofs poked his camera out of the blind, the lens hood instantly became coated with bat droppings. To see more of his work, visit www.theoallofs.com.

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AT THE MUSEUM

Columbus's Pearls

The discovery of vast oyster beds in the New World generated a "pearl rush" whose bounty flooded European markets.

By Neil H. Landman, Paula M. Mikkelsen, Rüdiger Bieler, and Bennet Bronson

Inspired by greed, a messianic desire to convert the world to Christianity, and fierce competition with the oceangoing Portuguese, King Ferdinand and Queen Isabella of Spain sponsored the Genoese explorer Christopher Columbus in an "enterprise of the Indies": finding a new route to the riches of the Orient. Under the contract, Columbus, as Admiral of the Ocean Sea, was granted authority over all the lands he discovered, as well as 10 percent of the value of all goods obtained. In turn, the monarchs made a list of what they expected. By chance or design, pearls were the first item on this list.

Columbus set sail westward in 1492, made landfall in the Bahamas, and then explored the coasts of Cuba and of Hispaniola (the island comprising modern-day Haiti and the Dominican Republic). After establishing the settlement of La Navidad on Hispaniola, Columbus returned to Spain in triumph, with gold, cotton, and Indians to be baptized, but without pearls. Not until his third trip, in 1498, when he reached the South American mainland, did Columbus finally find the long-sought supply of pearls—in what is now Venezuela, along the Gulf of Paria near the mouth of the Orinoco River. Noticing that the women at one Indian village there wore bracelets of "pearls or baroque pearls of high quality," Columbus bartered for these ornaments with needles, buttons, scissors, and broken majolica plates and asked about the source of the pearls. The natives gestured to the north and west.

He sailed on, passing the islands of Cubagua and Margarita, sites of what would ultimately become known as the Pearl Coast, the richest pearl grounds in the Americas. By coincidence, he gave Isla de Margarita that name—the Greco-Latin word for "pearl"—to honor Infanta Margarita of Austria, who was engaged to marry the heir to the Spanish throne. Once back in Hispaniola, Columbus became so embroiled in mediating colonial politics that he sent two ships back to Spain on their own, carrying letters that mentioned nothing about the Venezuelan pearls.

His returning sailors, however, privately sold the pearls they had acquired, and the news of this reached the Spanish court. Possibly suspecting that Columbus had kept other pearls for himself and disgruntled with his inept handling of the political situation on Hispaniola, his transport of slaves to Spain, and his reported cruelty to the sailors and West Indian natives, Ferdinand and Isabella had Columbus put in chains and returned to Spain in 1500. Released the following year, Columbus embarked on his fourth and last voyage in 1502. This time he followed the east coast of Central America, stopping en route in what are now Panama and Honduras but returning to Spain in 1504, again without pearls.

By the time Columbus died in 1506, his voyages had already initiated a "pearl rush" that was to last for the next 150 years. The first to profit were his sailors, among them Peralonso Niño, former pilot of the ship *Santa María,* who in 1499 received royal permission to explore the Pearl Coast, in clear contravention of the agreement giving Columbus exclusive authority. The chronicler Peter Martyr d'Anghiera, chaplain to Ferdinand and Isabella, recorded that Niño brought back "96 pounds of pearls, some as large as hazelnuts, very clear and beautiful, though poorly strung."

At about the same time, Alonso de Ojeda, who had sailed on the first expedition, somehow obtained Colum-

"Pearls"

An exhibition on the natural and cultural history of pearls opens at the American Museum of Natural History on October 13, 2001, and runs through April 14, 2002. Organized by AMNH in collaboration with the Field Museum in Chicago, "Pearls" is made possible through the generous support of Tasaki Shinju.

From *Pearls: A Natural History,* by Neil H. Landman, Paula M. Mikkelsen, Rüdiger Bieler, and Bennet Bronson. © 2001 by the American Museum of Natural History, the Field Museum, and Harry N. Abrams. Reprinted by permission of the publishers.

bus's map of the South American mainland and, accompanied by a then-unknown Italian, Amerigo Vespucci (whose account of the voyage would later give the continent his name), returned to the Pearl Coast. He landed on Isla de Margarita and explored Aruba, Bonaire, and Curaçao before moving on to Hispaniola and the Bahamas, obtaining about sixty pounds of pearls.

The quest for pearls soon expanded. Vasco Núñez de Balboa of Spain sailed still farther west, crossing the Isthmus of Panama in 1513. Upon reaching the Pacific coast, he encountered natives wearing pearls. When asked about the source of these riches, the chief responded that the best pearls came from Tararequí in the Gulf of Panama, now called the Archipiélago de las Perlas. As word of Balboa's discovery spread, other Spaniards headed for the Gulf of Panama and returned with sackfuls of pearls. Like those from Venezuela, most Panamanian pearls were destined for Spain.

Once the supply of pearls available through trade was exhausted, the Spanish began organizing pearl-harvesting ventures involving the use of slaves as pearl divers. When Christopher Columbus's son Diego became governor of Hispaniola in 1508, he established the first permanent pearl-fishing settlement on Isla Cubagua. Pearl fishing quickly expanded into other areas of the region, including Isla de Margarita and Isla Coche and eventually all the way to Cabo de la Vela in present-day Colombia. In 1535 Gonzalo Fernández de Oviedo y Valdés, in his *Natural History of the West Indies,* gave the most complete description of pearl diving in the region at that time:

Many Indians working in groups . . . leave the island of Cubagua . . . and go out in a dugout or boat early in the day to where they think they will find a large quantity of pearls. There they anchor the boat, in which one Indian remains, and he keeps the boat as still as he can. The others dive to the bottom. After some time, an Indian will return to the surface and deposit in the boat the oysters in which the pearls are found. He rests a while, takes a bite to eat, and once more he enters the water to stay as long as he can, finally returning with more oysters. . . . Sometimes when the sea is rougher than the pearl fisher would like—and also because naturally when a man is working underwater at a great depth, a diver's feet want to rise—it is only with difficulty that the worker can remain on the bottom any length of time. Under such conditions, the Indians use two large stones tied together with a cord, which they place over their shoulders, one on each side, and enter the water. . . . When he wants to rise to the surface, he merely drops the stones.

DETAIL OF PORTRAIT BY ALONSO SANCHEZ COELLO. KUNSTHISTORISCHES MUSEUM, VIENNA. PHOTOGRAPH BY ERICH LESSING; ART RESOURCE

Isabel de Valois, wife of Philip II of Spain, in a pearl-encrusted gown

Working conditions were extremely harsh. Diving bosses, known as *rancheros* or *patrones,* employed teams of four to seven divers per canoe under the supervision of a majordomo. They dived to depths of eight fathoms (forty-eight feet). A diver did not last long on the Pearl Coast, especially in the early years. In 1516 Spain's new king, Carlos V, responding to appeals by the priest Bartolomeo de Las Casas for more humane treatment of the Indians, issued regulations including the maximum hours and depth of diving per day and the minimum requirements for food and lodging. These rules were ignored often enough that further royal edicts became necessary. One such edict imposed the death penalty on anyone forcing a free Indian to become a pearl diver:

Because report has been made to us that, owing to the pearl fisheries not having been conducted in a proper manner, deaths of many Indians and Negroes have ensued, We command that no free Indian be taken to the said fishery under pain of death. . . . If, however, it should appear to them that the risk of death cannot be avoided by the said Indians and Negroes, let the fishing of the said pearls cease, since we value much more highly (as is right) the

JACKIE BECKETT, AMNH

In a 1594 engraving, Theodor de Bry depicted pearl fishing off the islands of Margarita and Cubagua. The area was a primary source of pearls in the sixteenth century.

preservation of their lives than the gain which may come to us from the pearls.

Many millions of Venezuelan pearls were collected in the first half of the sixteenth century, virtually flooding European markets. From the ports of Santo Domingo, Cartagena, and Havana, vessels laden with their precious cargoes of pearls and gold set sail for Spain, a trip fraught with danger from several sources. Some ships sank at sea in tropical hurricanes. Other ships were preyed upon by pirates, whose numbers increased during the sixteenth century. Seville became the center of the pearl market, a position Venice had claimed in previous centuries. Garcilaso de la Vega wrote that pearls from the West Indies were so abundant in Seville "that they were sold in a heap in the India [custom] house . . . just as if they were some kind of seed."

Pearls, a symbol of wealth and power, became an obsession among the elite. Without serious competition from other gems (sophisticated faceting techniques for precious stones were not developed until the mid-seventeenth century), pearls were unrivaled. In Europe, enriched by the loot of the Age of Discovery, conspicuous consumption rose to unprecedented levels.

Portraits of European royalty at the time display a wealth of pearls on clothing and in jewelry. Alonso Sánchez Coello's portrait of Isabel de Valois, third wife of Philip II of Spain, carefully renders the large pearls adorning her headdress, necklace, and belt and sewn along her collar, bodice, and shoulders. In another portrait, Catherine de Medici, queen of France in the mid-sixteenth century, is shown with round white pearls on her dress, in addition to a pearl headdress, necklace, and earrings. One of the most famous pearls from American waters is La Peregrina (often called "The Incomparable"). This pear-shaped white gem, weighing about ten grams, was reputedly a wedding gift from Philip II of Spain to his second wife, Mary I of England. Over the centuries, it passed through a succession of royal hands and, in 1969, was sold at auction to British actor Richard Burton, who gave it to his then wife, Elizabeth Taylor. She still possesses the jewel, although a few years ago she allegedly lost it in the plush white carpet of a hotel room, finding it eventually in her dog's mouth.

As the sixteenth century drew to a close, the known pearl beds of the Americas were increasingly depleted. Between 1513 and 1540, the number of pearls taken from Cubagua alone approached 120 million. Allowing one pearl per ten pearl oysters, this would mean that 1.2 billion oysters were harvested on that part of the Pearl Coast in just twenty-seven years, or approximately 40 million pearl oysters per year. Few species can recover from this kind of assault.

In the succeeding 400 years, there have been attempts to resuscitate the Venezuelan pearl industry, but most such endeavors have proved unsuccessful. Pearls are still occasionally found in oysters off the coast of Venezuela, however, a reminder of a time when Spanish ships plied those waters in search of pearls and the New World supplied the Old with an abundance of riches.

Neil H. Landman, of the American Museum of Natural History, is lead curator of the exhibition "Pearls," with co-curators Paula M. Mikkelsen, also of the American Museum of Natural History, and Rüdiger Bieler and Bennet Bronson, of Chicago's Field Museum.

Tasaki Shinju is proud to be the exclusive sponsor of "Pearls"
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MUSEUM EVENTS

OCTOBER 2
Lecture: "Evolution: The Triumph of an Idea." Carl Zimmer, author of the companion volume to the PBS *Evolution* series and columnist for *Natural History*. 7:00 P.M., Kaufmann Theater.

OCTOBER 3
Panel discussion: "Genetic Enhancement and Gene Therapy." Historian David Rothman, oncologist Eric Juengst, and legal scholar Dorothy Nelkin. 7:00 P.M., Kaufmann Theater.

OCTOBER 4, 8, 11, AND 15
Lectures: "Floral Diversity Past and Present," October 4, and "Ecological Biodiversity and Plants," October 11 (Biodiversity and Plants series). William Schiller, Museum botany lecturer. 7:00 P.M., Linder Theater. (The series is repeated on October 8 and 15 at 2:30 P.M.)

OCTOBER 4, 11, AND 15
Lectures in conjunction with the exhibition "Meeting God: Elements of Hindu Devotion": Curator Stephen P. Huyler; Mary McGee, director of Columbia University's Dharam Hinduja Indic Research Center; and others. 7:00 P.M., Kaufmann Theater. (October 4: Additional lecture by Stephen P. Huyler, AARP series, 2:00 P.M.; exhibition viewing, 6:00–7:00 P.M.)

OCTOBER 4, 11, AND 18
Lectures: "Sources of Information and Basic Geological Principles," October 4; "Rocks and Their Features," October 11; and "Landscape Classification and Geological Structures," October 18 (Geology for Travelers series). Geologist Sidney S. Horenstein. 7:00 P.M., Linder Theater.

OCTOBER 6
Exhibition opening: "The Butterfly Conservatory: Tropical Butterflies Alive in Winter." Hall of Oceanic Birds. Through May 27, 2002.

OCTOBER 10, 16, 23, AND 30
Lectures: "The Hudson: A Visual Journey," October 10; "Navigating Through History: Boats on the Hudson River," October 16; "The Hudson River Estuary: A Spawning Ground and Nursery," October 23; and "Bridges and the Creation of Greater New York," October 30 (Beyond Henry Hudson/AARP series). Historian Roger Panetta, of Marymount College, and Museum natural science instructor Uta Gore. 2:00 P.M., Kaufmann Theater.

KEN HEYMAN

Focus on the family: *Portrait of a Danish Mother and Child*, from the Margaret Mead Centenary Exhibition, which opens in the Akeley Gallery on October 27

OCTOBER 13, 17, 23, AND 25
"Pearls," an exhibition in Gallery 4, opens on October 13. Lectures: "All About Pearls: Their Nature and Culture," Neil H. Landman, curator of the exhibition, and co-curator Paula M. Mikkelsen, October 17; "Pursuing the Dragon: The Mystery of the Orange Pearls of Vietnam" (AARP series), gem collector Benjamin Zucker and author James Traub, October 23; and "Understanding and Appreciating the Queen of Gems—The Pearl," Antoinette Matlins, author of *The Pearl Book*, October 25. 7:00 P.M., Kaufmann Theater.

OCTOBER 15
Lecture: "The Universe at Midnight" (Distinguished Authors in Astronomy series). Astronomer Ken Croswell. 7:30 P.M., Space Theater, Hayden Planetarium.

OCTOBER 18
Lecture: "In the Company of Gorillas." Biologist Amy Vedder, director of the Wildlife Conservation Society's Africa Program. 7:00 P.M., Kaufmann Theater.

OCTOBER 21
Children's workshop and exhibition visit: "Pearls: Legend and Lore." Artist and art historian Ita Aber. 10:30 A.M.–1:30 P.M. Venue to be announced at registration. (For ages 10 and 11.)

OCTOBER 27
Exhibition opening: "Margaret Mead Centenary Exhibition." Photographs by Ken Heyman, from Mead and Heyman's *Family* (1965). Akeley Gallery. Through May 2002.

OCTOBER 29
Lecture: "Quasar Absorption Lines: Seeing Ghosts in the Universe" (Frontiers in Astrophysics series). Astronomer Jane Charlton. 7:30 P.M., Space Theater, Hayden Planetarium.

OCTOBER 30
Lecture: "The Evolution Explosion." Biologist Stephen Palumbi. 7:00 P.M., Kaufmann Theater.

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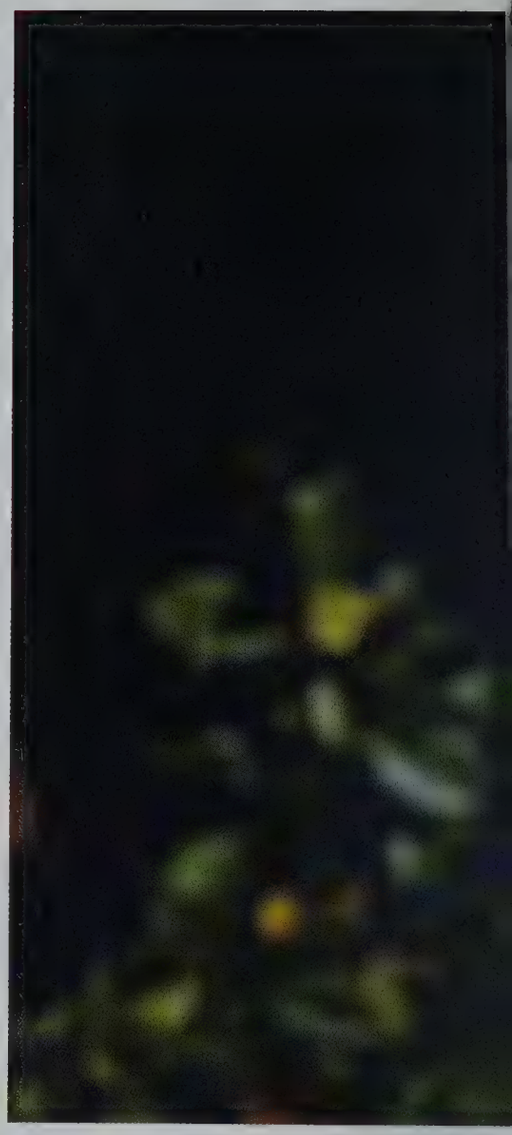
IN THE FIELD

A Squirrel's Glide to a Long Life

Longevity secrets of a fly-by-night mammal

By Peter J. Marchand



An hour or so after sundown, my students and I stepped outside our lodge in the White Mountains of New Hampshire to look at the night sky. The October evening was settling in crisp and clear, the brighter stars already showing through the waning twilight. We were gazing upward, hoping to see a meteor or two, when a shadowy silhouette caught my eye. I turned just in time to see a flying squirrel glide into the darkness of the forest understory. Turning our attention to the woods, we all stood motionless, straining to see the squirrel again. Soon another one appeared, and then another, emerging to forage. It was their time, and we were in the right place.

I couldn't tell for sure whether we were watching northern flying squirrels *(Glaucomys sabrinus)* or the smaller southern flying squirrels *(G. volans)*. The ranges of these species overlap along the Appalachian Mountains from the southern United States to New England, and it is difficult enough to tell these squirrels apart in daylight, let alone in the dark. Ecologically, however, they behave much the same, and taken together the two species are quite possibly the most common of all squirrels in the eastern United States, even in wooded parks and urban residential areas. When times are good for flying squirrels, they may number as many as eleven per acre in the spruce-fir and hardwood forests of the Appalachians. For most other squirrels in the wild, this would be a veritable crowd, but flying squirrels break nearly all the rules with their gliding locomotion, their strong dietary preference for underground truffles, and their unusual longevity. For *Glaucomys,* eleven is mere company.

Numbers, in fact, contribute significantly to the success of these gregarious little squirrels. Weighing only two to four ounces and staying active all year, they have little natural resistance to the cold they may encounter even in the southern Appalachians. But what these animals lack in size and insulation, they make up for in sociability. To cope with winter's chill, flying squirrels huddle together in grass-, moss-, or bark-lined tree cavities. While congregations of about ten are the norm, groups may swell to twenty or even fifty individuals, particularly among southern flying squirrels. And the benefits are considerable. I once slipped a small temperature probe into a tree cavity that I knew was being used by flying squirrels. Weeks later, on a cold January day, I checked on the cavity with my students. As I expected, the temperature in the nest was well above that of the outside air. (Differences of thirty or more degrees are commonly reported.) While we were standing below the tree hole, watching our remote recorder, the temperature suddenly shot up ten degrees, due to a burst of unseen squirrel activity, and then settled back down. My students had much fun speculating on the nature of this heat-generating action. Although it was a few weeks early for reproductive behavior, cavity sharing may indeed have benefits beyond simply staying warm.

It is not by their social habits alone, however, that *Glaucomys* achieve their relative abundance. They also age more slowly than do other squirrels and, with a life span of ten or more years, live longer than expected for a small mammal—as much as 50 percent longer than, say, ground squirrels of comparable size. This longevity may be tied to their exceptionally low metabolism. Joseph Merritt, of the Carnegie Institute's Powdermill Biological Station in western Pennsylvania, recently found that the average resting metabolic rate of

KIM TAYLOR; BRUCE COLEMAN INC.

A leap in the dark: A southern flying squirrel deploys its broad, rudderlike tail and its gliding membranes, which stretch from wrist to ankle. These squirrels' large eyes enhance night vision.

southern flying squirrels was 38 percent lower than expected, based on previous studies of similar-sized mammals. Other tree squirrels occupying the same geographic range as flying squirrels typically have rates at the opposite end of the spectrum—up to four times higher than predicted for their body mass.

While it may seem intuitive that aging and metabolism would be related, this is not necessarily the case among other long-lived animals. Although many reptiles seem to support the "live slow, live long" notion, animals such as hummingbirds can also reach a relatively great age, despite their high metabolic requirements. Perhaps other life-history traits—flying or gliding, for example—favor longevity. Birds in general, excepting poor flyers such as grouse and turkey, have life spans two or three times longer than mammals of comparable size. And among mammals, bats live the longest relative to body size. In fact, most of the world's gliding mammals appear to outlive their earthbound counterparts by a significant margin. For flying squirrels in particular, the combination of gliding, nocturnal habits, and tree-cavity nesting may confer significant advantages by reducing their vulnerability to predation. And in the evolutionary game, safety, rather than low metabolic rate, could make the difference.

Last fall I accompanied Joe Merritt on his rounds at the Powdermill reserve. For twenty years Joe has weighed, marked, and released flying squirrels that enter live traps attached to tree trunks. This time, in the space of only an acre or so, he caught three new, unmarked southern flying squirrels. Judging by their weight—all three were less than two ounces—these young squirrels were from a pair's second litter of the summer, born in August. Already, however, they were adept gliders and had become familiar with their territory. As Joe released the first one, it climbed quickly up a tall, straight yellow poplar. At a height of nearly seventy feet, it turned face downward and launched unhesitatingly into a long, graceful glide across a stream. The squirrel clearly knew just where it wanted to go. Steering with all four limbs and using its tail as a rudder, it navigated toward and landed directly on its target: the trunk of a dead white oak. It scampered forty feet up the oak, then disappeared under a slab of loose bark that more than likely concealed a nest cavity. It was a treat to observe this nocturnal creature in broad daylight, and my thoughts immediately went back to that evening in New Hampshire when my students and I felt so privileged to have caught just a glimpse of this very common but seldom seen tree squirrel.

Peter J. Marchand is a research ecologist at the Catamount Institute in Woodland Park, Colorado.

UNIVERSE

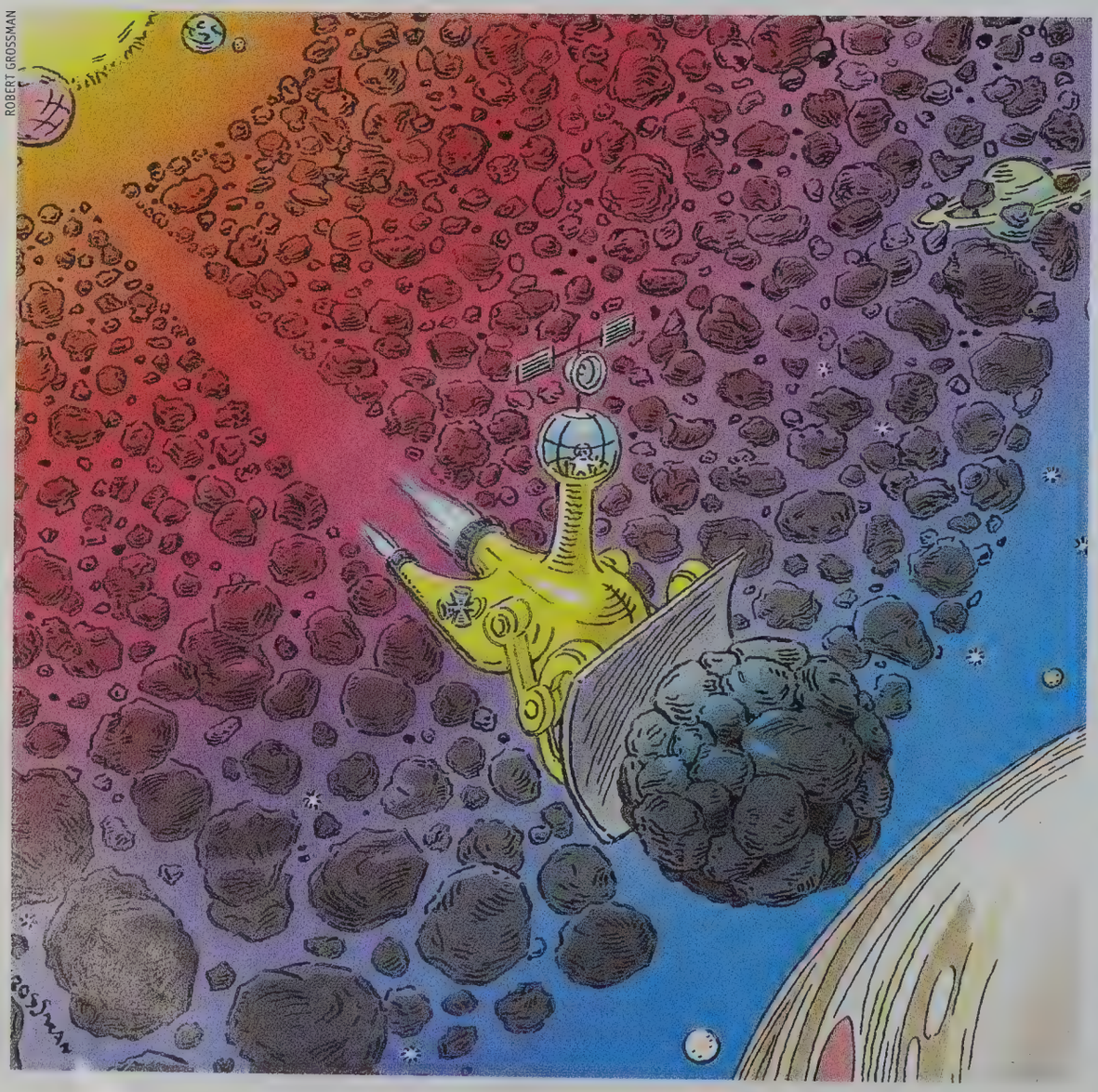
Between the Planets

The emptiness of interplanetary space has been much exaggerated.

By Neil deGrasse Tyson

From a distance, our solar system looks empty. If you enclosed it within a sphere large enough to contain the orbit of Neptune, then the volume occupied by the Sun, the planets, their moons, and all asteroids would take up little more than one-trillionth of the space. When viewed close-up, however, the space between the planets contains all manner of pebbles, chunky rocks, ice balls, dust, streams of charged particles, and far-flung probes. The space is also permeated by monstrous gravitational and magnetic fields.

Space is so not-empty that Earth, during its eighteen-mile-per-second orbital journey, plows through hundreds of tons of interplanetary debris per day—much of it no larger than a grain of sand. Nearly all of it burns in Earth's upper atmosphere, slamming into the air with so much energy that it vaporizes on contact. The larger, golf-ball-sized pieces of debris heat fast but unevenly and often shatter into smaller pieces before they vaporize. Still larger pieces get their surfaces singed but otherwise make it all the way to the ground intact. You'd think that by now, after 4.6 billion trips around the Sun, Earth would have vacuumed up all possible debris in its orbital path.



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But things were once much worse. For half a billion years after the formation of the Sun and its planets, so much junk rained down on Earth that the energy from the impacts sustained a heated atmosphere and a molten surface.

One hunk of junk in particular was quite substantial—it's what led to the formation of the Moon. The unexpected paucity of iron and other high-mass elements in the Moon (deduced from lunar samples returned by Apollo astronauts) indicates that the Moon most likely burst forth from Earth's iron-poor crust and mantle when our

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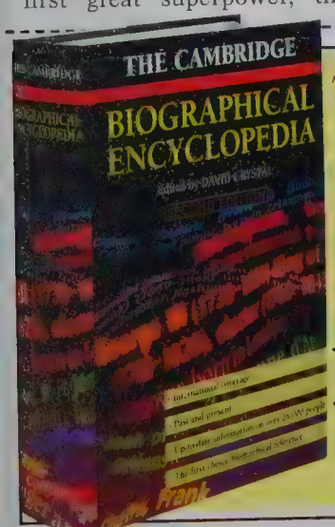

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planet had a glancing collision with a wayward, Mars-sized protoplanet. The orbiting flotsam resulting from this encounter coalesced to form our lovely, low-density satellite. Apart from this newsworthy event, the period of heavy bombardment that Earth endured during its infancy was not unique in the solar system: all the planets and other large bodies sustained similar damage, with the airless, uneroded Moon and Mercury preserving much of the cratered record from this period.

Not only is the solar system littered with the detritus of its formation, interplanetary space also contains rocks of all sizes that were thrust from Mars, the Moon, and probably Earth as the ground recoiled from high-energy impacts. Computer studies of meteor strikes demonstrate conclusively that surface rocks near ground zero can get thrown upward with enough speed to escape a celestial body's gravitational tether. Meteorites originating from Mars turn up so often on Earth that scientists have concluded that as much as a thousand pounds of Martian rocks may rain down on us each year. Perhaps the same amount reaches Earth from the Moon. Indeed, we didn't have to go there to retrieve Moon rocks, although we didn't know this during the Apollo program. Plenty come to us, even if they are not of our choosing.

If Mars ever harbored life—billions of years ago, when its surface was wet with liquid water—then unsuspecting bacteria stowed away in the nooks and crannies (especially the crannies) of the ejected rocks could have traveled to Earth for free. We already know that some varieties of bacteria can survive long periods of hibernation as well as the high doses of ionizing radiation to which traveling microorganisms would have been exposed en route to Earth. So the existence of space-borne bacteria is neither a crazy idea nor pure science fiction. The concept even has an important-sounding name: panspermia. If Mars spawned life before Earth did, and if simple life traveled from Mars on an ejected rock and seeded Earth, then we may all be descendants of Martians. Awareness of this fact may also obviate environmentalists' fears about astronauts sneezing on the red planet's surface, spreading their germs on the alien landscape.

Most of the solar system's asteroids live and work in the main asteroid belt, a somewhat flat zone between the orbits of Mars and Jupiter. Often drawn by artists as a region of cluttered, floating rocks in the plane of the solar system, the asteroid belt's total mass is less than 5 percent that of the Moon, which is itself not much more than 1 percent the mass of Earth. Sounds insignificant. But accumulated perturbations of the asteroids' orbits continually feed a deadly subset of objects, perhaps a few thousand, whose eccentric paths intersect Earth's orbit. A back-of-the-envelope calculation demonstrates that most of them will hit our planet within the coming 100 million years. Those larger than about a mile across will bang into Earth with enough energy to destabilize our ecosystem and put most land species at risk of extinction. That would be bad.

Meteorites of Martian origin are regularly discovered on Earth. As much as a thousand pounds of rocks from the red planet may rain down on us each year.

Asteroids are not the only space objects that pose a risk to life on Earth. The Kuiper belt is a circular, comet-strewn swath of real estate that begins just beyond the orbit of Neptune, includes Pluto, and extends perhaps as far again from Neptune as Neptune is from the Sun. The Dutch-born American astronomer Gerard Kuiper advanced the idea that frozen leftovers from the formation of the solar system reside in the cold reaches of space beyond Neptune's orbit. Without a massive planet to fall upon, most of these comets will orbit the Sun for billions more years. Like their counterparts in the asteroid belt, a subset of Kuiper belt objects travel on eccentric paths that cross the orbits of other planets. Pluto and its ensemble of siblings called Plutinos cross Neptune's path around the Sun. Other Kuiper belt objects plunge all the way down to the inner solar system, crossing planetary orbits with abandon. One of these is Halley, the most famous comet of them all.

Far beyond the Kuiper belt, extending halfway to the nearest stars, lives a spherical reservoir of comets called the Oort cloud, named for Jan Oort, the Dutch astronomer who first deduced its existence. This zone is responsible for the long-period comets, whose orbital periods last far longer than a human lifetime. Unlike Kuiper belt comets, Oort cloud comets can rain down on the inner solar system from any angle and any direction. The brightest comets of the 1990s—comets Hale-Bopp and Hyakutake—both emerged from the Oort cloud and are not coming back this way anytime soon.

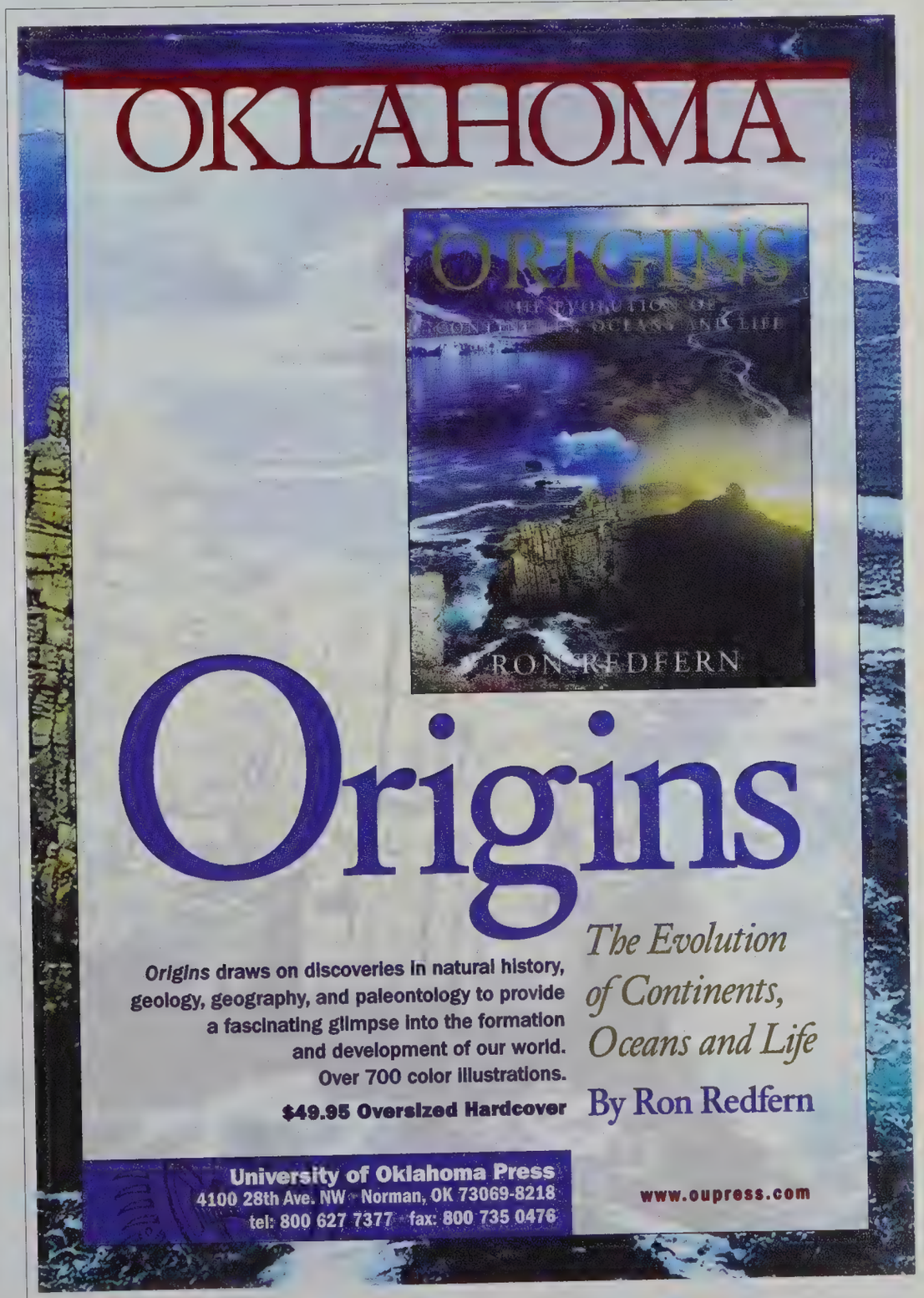
Not everything that fills interplanetary space is visible. If we had eyes that could see magnetic fields, Jupiter would look ten times larger than the full Moon in the sky. Spacecraft that visit Jupiter must be designed to remain unaffected by this powerful magnetic field. As English physicist Michael Faraday demonstrated in the 1800s, if you pass a wire across a magnetic field, you generate a voltage difference along the length of the wire. For this reason, electric currents can be induced within fast-moving metal space probes. These currents happen to generate a magnetic field of their own that interacts with the ambient magnetic field in such a

way as to retard the space probe's motion. This might be the cause of the mysterious slowing-down of the two *Pioneer* spacecraft as they exit the solar system. Neither *Pioneer 10* nor *Pioneer 11,* both launched in the early 1970s, has traveled as far into space as our dynamic and kinematic models predicted they would have by now. If we subtract the possible effects of leaky fuel tanks and space dust en route, the best explanation for this pokiness becomes magnetic interaction—in this case, with the Sun's field.

Once upon a time, there were fifty-six moons among the planets in the solar system. When I woke up one morning in 1995 to learn that another four had been discovered around Saturn, I decided I would no longer keep count. All I care about now is whether any of them would be fun places to visit or study. By some measures, the solar system's moons are much more fascinating than the planets they orbit. In Jonathan Swift's 1726 classic, Lemuel Gulliver learns from the cloud-dwelling scientists of Lagado that Mars has two Moons. Problem is, these two potato-shaped bodies were not discovered until a century and a half later. Earth's Moon is about 1/400 the diameter of the Sun, but it's also 1/400 as far from us, making the Sun and the Moon the same size in the sky—a coincidence not shared by any other planet-moon combination in the solar system, and one that allows for uniquely photogenic total solar eclipses. Earth has also tidally locked the Moon, leaving it with identical periods of rotation on its axis and revolution around Earth. Wherever and whenever this locking happens, the moon shows only one face to its host planet.

Jupiter's system of moons is replete with oddballs. Io, Jupiter's closest satellite, is tidally locked and structurally stressed by its interactions with Jupiter and with the planet's other moons—which pump enough heat into the little orb to render its interior rocks molten. Io is the most volcanically active place in the solar system. Jupiter's moon Europa suffers from the same heating mechanism, which has melted its subsurface ice, leaving a liquid ocean below. (An artist coworker of mine once asked whether alien life-forms from Europa are Europeans. The absence of any other plausible answer forced me to say yes.) Close-up images of the surface of Miranda, one of Uranus's moons, reveal badly mismatched patterns, as though the poor moon had blown apart and the pieces were hastily glued back together. The origin of these exotic features remains a mystery but may be due to something simple, such as the uneven upwelling of ice sheets.

Pluto's lone moon, Charon, is so large and so close to Pluto that the two bodies have each tidally locked the other, making their rotation peri-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ods as well as their periods of revolution identical.

By convention, planets are named after Roman gods, and moons are named after lovers, friends, and enemies of the Greek counterparts of these Roman gods. The classical gods led complicated social lives, so there is no shortage of characters to draw on. The lone exception to this rule applies to the moons of Uranus, which are named for assorted protagonists in English Lit. Astronomer Sir William Herschel was the first person to discover a planet beyond those easily visible to the naked eye, and he was ready to name the new planet after the king under whom he faithfully served. Had Sir William succeeded, the planet list would read: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Neptune, and George. Fortunately, clearer heads prevailed and the classical name Uranus was adopted some years later. But his original suggestion—to name the moons after characters in William Shakespeare's plays and Alexander Pope's poems—remains the tradition to this day. Among Uranus's nearly two dozen moons we find Ariel, Cordelia, Desdemona, Juliet, Ophelia, Portia, Puck, and Umbriel.

Streaming toward objects in the solar system is the solar wind. The Sun loses material from its surface at a rate of 200 million tons per second (which happens to match closely the flow rate of water through the Amazon basin). Most of this material takes the form of high-energy charged particles. Traveling up to a thousand miles per second, they fly through space and are deflected by planetary magnetic fields. The particles spiral down toward the planets' north and south magnetic poles, colliding with gas molecules and leaving the atmospheres aglow with colorful auroras. The Hubble Space Telescope has spotted auroras near the poles of both Saturn and Jupiter. On Earth, the aurora borealis and aurora australis (the northern and southern lights) serve as intermittent reminders of how nice it is to have a protective atmosphere.

Earth's atmosphere is commonly described as extending a couple dozen miles above Earth's surface. Satellites in "low" Earth orbit typically travel between 100 and 500 miles up and complete an orbit in about ninety minutes.

Satellites in low orbit can be dragged down by scattered molecules of atmospheric gas. Only intermittent boosts of power prevent a fall back to Earth.

While you can't breathe at those altitudes, some atmospheric molecules remain—enough to slowly drain kinetic energy from moving satellites. To combat this drag, satellites in low orbit require intermittent boosts lest they burn up in the atmosphere. The most sensible way to locate the edge of our atmosphere is to find where its density of gas molecules equals the density of gas molecules in interplanetary space. By this definition, Earth's atmosphere extends out thousands of miles. Orbiting high above this level—23,000 miles up, one-tenth the distance to the Moon—are the communications satellites. At this special altitude, where interference from Earth's atmosphere is not a factor, the satellites take twenty-four hours to complete one revolution around Earth. With an orbital speed that precisely matches the rotation rate of Earth, these satellites effectively hover, which makes them ideal for relaying signals from one part of Earth's surface to another.

Newton's laws specifically state that although the gravity of a planet gets weaker and weaker the farther you travel from it, at no point does the force of gravity reach zero. The planet Jupiter, with its mighty gravitational field, slings out of harm's way many comets that would otherwise wreak havoc on the inner solar system. Jupiter acts as a gravitational shield for Earth, allowing us 100-million-year stretches of relative peace and quiet. Without Jupiter's protection, terrestrial life would have had a hard time becoming interestingly complex, remaining at risk of extinction from a devastating impact.

Nearly every probe launched into space has exploited the gravitational fields of planets. The *Cassini* probe, for example, now en route to Saturn, was launched from Earth on October 15, 1997, and has since been gravitationally assisted twice by Venus, once by Earth (on a return flyby), and once by Jupiter. As with a multicushion billiard shot, trajectories from one planet to another are common. Our tiny probes would otherwise not have enough speed and energy to reach their destinations.

I am now personally accountable for some of the solar system's interplanetary debris. In November 2000 the main-belt asteroid 1994KA, discovered by David Levy and Carolyn Shoemaker, was named Tyson 13123 in my honor. While I enjoyed the distinction, there's no particular reason to get bigheaded about it; plenty of asteroids have familiar names, such as Jody, Harriet, and Elliot. There are even asteroids out there named James Bond, Merlin, and Santa. Passing the 20,000 mark, the asteroid count might soon challenge our capacity to name these objects. Whether or not that day arrives, I enjoy a curious comfort knowing that my chunk of cosmic debris is not alone as it litters the space between the planets, joined by a long list of other chunks named for real and fictional people.

I'm also glad that at the moment, my asteroid is not headed toward Earth.

Astrophysicist Neil deGrasse Tyson, is the Frederick P. Rose Director of New York City's Hayden Planetarium and is a visiting research scientist at Princeton University.

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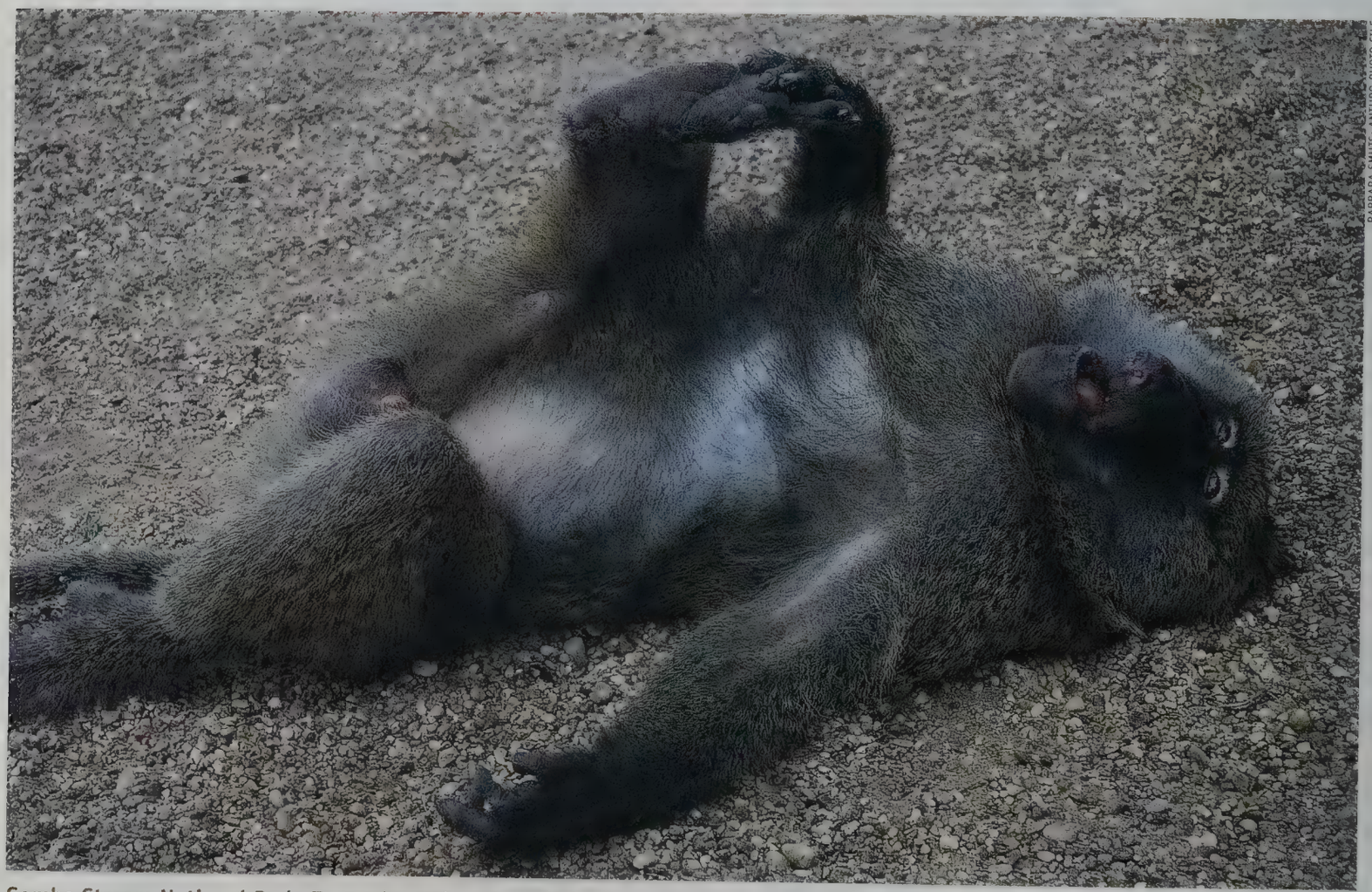
NATURALIST AT LARGE

Coming Home

Under the tutelage of baboons, a scientist learns to appreciate her animal self.

By Barbara Smuts



BARBARA SMUTS; ANTHRO-PHOTO FILE

Gombe Stream National Park, Tanzania: Bofu, an adult male baboon, takes a break.

I've joined chimpanzees carousing in the hot, rugged hills of western Tanzania, baboons strolling across the golden grasses of highland Kenya, gorillas munching their way through the foggy mountains of central Africa, and dolphins gliding through the aquamarine Indian Ocean. In all these worlds I felt at home. I loved the freedom, the feel of the sun, the smell of the air, the tranquillity of dusk, the beauty of my animal companions.

Over the past thirty years, wild animals and places have taught me things about human nature—and about my own nature in particular—that I could never have anticipated back when I chose to become a biologist. At first, I approached wild primates as subjects to be studied. The places they lived and hunted were "habitats" that I needed to know about simply because they influenced the animals' behavior. Although I loved these creatures (and their surroundings), between us lay an uncomfortable gap—an outgrowth of my scientific orientation. Then something started to happen that would help bridge the gap. Slowly, imperceptibly at first, another identity began to assert itself within me, an identity I will refer to as "the animal," though really it requires no name. It is simply myself.

During my first two years in the field, my scientist self and my animal self lived together without speaking. The animal didn't in any way interfere with the scientist's activities; in fact, she often helped. She noticed things that

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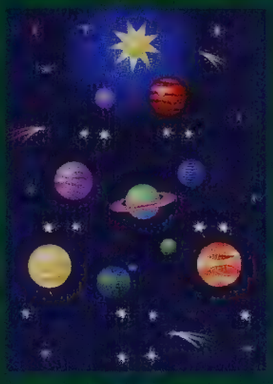

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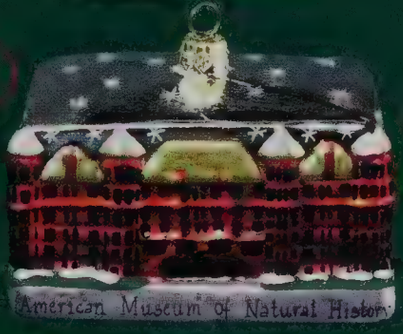

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the scientist missed, such as the tension in the air before a male chimpanzee began to display or the longing of a female baboon for her male friend. She knew these things not in words but with a keen, intuitive awareness. Later, back at the university, I began to reflect on the animal. I wondered who she really was, and I wondered what I might learn about other animals and my fellow humans from examining this aspect of myself. I wanted to know the animal better, for both scientific and personal reasons. But to know her better, I had to evoke her more often and more intensely. The scientist would have to move over and make more room for the animal.

When I returned to the field, I gave some time over entirely to the animal. The scientist conducted observations of foraging baboons; the animal joined the baboons on exciting adventures to unexpected places: same journey, more fun. On my own, I could easily have become lost in this vast place with no trails, no signs pointing homeward, and no people. But I was lucky; the baboons were expert guides, and I abandoned myself to their far superior knowledge. They taught me things like how and when to scan the horizon for predators, shortcuts to water sources, the best places to find mushrooms and ripe fruit, the coolest places for naps, and the location of rock overhangs for shelter from the rain. I was regaining the kind of knowledge that belonged to my ancestors, and I was doing so in the place where, several million years ago, humans first evolved. It felt like coming home.

The baboons were expert guides, and I abandoned myself to their far superior knowledge.

Nevertheless, in the early days I tried to understand my animal self in scientific terms, focusing especially on what I knew about human evolution. Comparing my upright stance to the baboons' four-footed gait, I tried to figure out the advantages of bipedalism. When I froze in the morning and burned in the sun later the same day (my baboon field site near Gilgil, Kenya, was more than a mile above sea level), I wondered why we humans ever lost our protective coat of hair. Gradually, however, my awareness shifted from the thoughts filling my head to moment-to-moment reality. With each step, I could feel how I was designed to flourish in the wild. My eyes, like yours, are made to scan for bright-colored fruit and for predators moving in the distance. My ears are made to notice a rustle in the grass or the faint cry of a baby. My feet are made to feel the texture of the ground. My hands are made to grasp and to caress, my arms to throw and embrace, my heart to beat fast or slow in response to the matrix of sounds, sights, and scents in which I am enveloped. And my whole being is made to stay open every moment to every sensory nuance.

Over time, my animal self grew more confident. The animal wanted to do things she was made for: walking for miles in a slow, steady rhythm; snacking on seeds and fruit throughout the day; sleeping through the heat of the afternoon. Because I was designed to do such things, I tended to do them rather well and with great enjoyment. Nowadays when I travel by foot in wild places, I rarely need to stop and think, "Where should I go? What should I eat? Is it time to make camp for the night?" Instead I respond from moment to moment, surrendering gently to instinct—not as mindless, reflexive action but rather as action rooted in the certainty of knowledge, deep and old.

The actions of wild animals stem from this place of deep knowing. A chimpanzee may respond to a leopard's threat with a highly inventive act that no chimpanzee has ever used before, but the awareness of the need to respond quickly and defensively arises without effort, without pause. Similarly, a mother baboon knows how to nurse and comfort her baby without instruction. Even when skills depend greatly on experience, on learning, the learning itself is guided by ancient knowledge about what to learn and how to learn it. This kind of knowledge exists in all of us, waiting to be recognized and used.

BARBARA SMUTS; ANTURO OUOTA CIS

Gilgil, Kenya: The author and a baby baboon

Trusting such deep knowing is, I'm convinced, a good way to live. Of course, the wild animals I lived with got grouchy, went hungry, and suffered fear and pain and loss. But these creatures seemed quite happy most of the time. Each morning as baboons descend from their sleeping places, all troop members, but especially females and young, enthusiastically greet one another with gentle pats, hugs, and other affectionate touching. Sometimes a greeting turns into play, as when a saucy adolescent female ends her hello to an adult male with a somersault flourish. As the day heats up, baboons are given to taking long breaks in attractive locales, where they indulge their passion for lying in the shade with a foot or two in the air. This is a favorite time for grooming, which seems to relax the groomee the way a good massage relaxes us. Every now and then, someone emits a deep, satisfied sigh. Off and on, a chorus of

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soft grunts ripples gently among the baboons, as though they concur about the agreeableness of their situation.

When I first went to the field, I viewed these siestas as valuable opportunities to gather data on who slept near whom. Later, I would sometimes lie around with them instead. Later still, I would sometimes lie around without them (that is, they were present but busy eating). Once I fell asleep surrounded by 100 munching baboons, only to wake up after half an hour—alone except for an adolescent male napping by my side. We blinked at each other and then he led me back to the rest of the troop, miles away.

By associating with baboons (as well as with chimpanzees, gorillas, dolphins, and others) and surrendering to my animal self, I learned how satisfying it can be just to be. This lesson has changed me, irrevocably. Although I still function as a scientist and enjoy doing so, the work no longer feels intrinsic to my identity. My identity now feels paradoxically both firmer and more fluid, more entwined with my surroundings.

We humans (at least in the West) tend to consider autonomy and community as opposite states of being, but I suspect that baboons, and perhaps many other animals, experience themselves as both distinct agents and a part of something bigger. There can be no doubt that baboons are distinct individuals—highly idiosyncratic characters, in fact, each and every one. I can recall Alex's long-limbed lope and Virgil's throaty bark. Each baboon has favorite foods (one alpha female, Dido, was crazy about mushrooms), favorite ways to take a nap (Boz liked to wrap his arms around a suitable-sized bush, leaning into it like a lover). Many had peculiar habits: Himalaya, a lusty female, used to capture the attention of a potential suitor by bending over and peering at him upside down, from between her legs; Triton, a young adult male, carried around scraps of rabbit fur gleaned from recent kills to hurl at the rumps of estrous females who ignored him.

I relished the animals' individuality because it made them so interesting to be with. In so doing, I developed a greater acceptance of and appreciation for my own idiosyncratic nature. I could see aspects of myself, both "good" and "bad," reflected in individual baboons. I identified with one mother's gentle treatment of her infant but also with another mother's impatient shove when the kid got in the way. I had no impulse to condemn "bad" traits in the baboons, because I could see clearly how each individual's distinct nature depended on a unique configuration of strengths and weaknesses. I began to try to apply the same accepting attitude toward myself.

Once I fell asleep surrounded by 100 baboons, only to wake up alone except for an adolescent male.

This was difficult when I thought in terms of my culturally constructed, specifically human identity; easier when I thought of myself as just another primate. In the same way, upon returning to civilization I tried to judge other people less. Again, this proved easier when I remembered that they, too, are just other primates, doing the best they can in a world ever more alien to their animal natures.

Although every baboon (or chimpanzee or dolphin) is a distinct, highly individuated self, each seems to exist simultaneously as self-in-community or even as self-in-communion. When the baboons responded to an intrusion into their home range by a neighboring troop, they could move as one toward the enemy, like a well-trained army. But they also expressed community when they were well fed and facing no threat. Gathering on their sleeping cliffs at night, the group would sing a song of gentle grunts, with the deep voices of the adult males, the softer voices of the females, and the high-pitched voices of the young blending in a harmony that seemed to express their delight at being part of a close-knit group.

Sometimes their sense of community seemed to move beyond the boundaries of their ordinary lives. I treasure one memory in particular. A troop of baboons in Gombe Stream National Park, Tanzania, were traveling to their sleeping grove late one afternoon, moving slowly down a stream punctuated by smooth boulders and still pools. Without any perceptible signal, everyone stopped and then sat, alone or in small clusters, gazing into the pools. Even the perpetually noisy, scrappy juveniles fell into silent contemplation. Half an hour later, again with no signal I could detect, they resumed their journey, in what felt to me like an almost sacramental procession. I was stunned by this mysterious expression of what I have come to think of as a baboon *sangha* (spiritual community).

A rhythm of change lies at the center of this account. My relationship with the natural world began with a longing to be in nature, a longing stemming in part from a sense of separation from nature. Over time, the feeling of separation dissolved. I discovered that I am as intrinsic a part of the wild landscape as are the baboons, and I learned that my body, like theirs, harbors the wisdom of the ages. This wisdom connects me to everyone and everything else, reminding me that every habitat is someone's dearest home. All of it is alive, and all of it deserves reverence.

Barbara Smuts, author of Sex and Friendship in Baboons *(Harvard University Press, 1999), teaches animal behavior in the psychology department of the University of Michigan. Her current research interests include greeting behavior in wild baboons and social play among domestic dogs.*

taking *flight*

Join the
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to some extraordinary
birding destinations

costa rica

If you're looking for an autumnal vacation that's a little more exciting than leaf peeking, take flight and join the fall migration to peek at some of the most breathtaking beauty in the world. You can take flight to Central Park in New York City and watch the hawks migrate south from Belvedere Castle, or you can take flight to Latin America and the Caribbean to find a colorful quetzal in Costa Rica. A birding vacation is the perfect fall getaway, a chance to experience nature's riches in a new and exciting way.

Christopher Columbus first gave Costa Rica her name: "rich coast." With only 20,000 square miles, Costa Rica is rich in biodiversity and natural beauty. The government has protected 30 percent of its territory in national parks and forest preserves, allowing visitors to take advantage of this incredibly rich coast. And with almost 850 species of birds, Costa Rica has long been famous among bird watchers.

Visitors usually fly into Costa Rica's Juan Santamaría International Airport, located in the capital, San José. Although San José was founded in the mid-1600s, it didn't become the nation's capital until the 1820s, after Costa Rica's independence from Spain. Make sure you spend at least a day in this bustling colonial city before heading out to explore the rest of the country. Your first stop in San José should be the offices of the Costa Rican Institute of Tourism. The ICT can help point you in the right direction and provide you with a map of the city to help you get your bearings.

After taking advantage of San José's lovely parks, cathedrals, and museums, you can take a day trip or several overnight trips to Costa Rica's Central Valley. The Reserva Forestal Cordillera Volcánica Central is made up of close to 165,000 acres of protected land, including three national parks and a variety of private and national forestry reserves. Here you can easily explore the Volcano Route between four of the area's volcanoes – Irazú, Turrialba, Barva, and Poás.

One of Costa Rica's newest ecotourism destinations is located only an hour out of San José, near Poás Volcano National Park. La Paz Waterfall Gardens offers visitors the choice of four hiking trails that wind around five waterfalls and through a tropical forest.

Before heading down to the falls, the trail first leads into a huge butterfly observatory. The enclosed structure allows butterflies to soar freely while visitors walk around the natural habitat. The next stop on the trail is a lovely hummingbird garden that 16 different species of hummingbirds call home. After exploring the Central Valley, you can find plenty of restaurants in San José to help extend the pleasures of the day. Nearly every cuisine in the world is represented, and each one will include typical "Tico" warmth and hospitality.

This special editorial/advertising supplement was created by the Natural History Special Sections Department and did not involve the magazine's editorial staff.
Writer: Stephanie Fekety Design: Maria Volpe Photography: Courtesy of the Instituto Costarricense de Turismo and the U.S. Fish and Wildlife Service.

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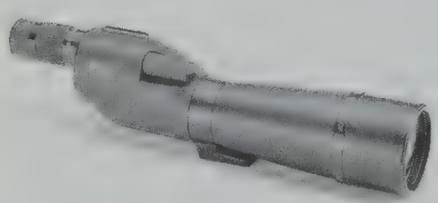

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Eagle Optics, the leader in supplying optic equipment to bird watchers, amateur astronomers, and outdoor enthusiasts, supports a number of nature festivals around the country, and this fall is no exception. On October 4 - 7, Eagle Optics is a proud sponsor of the Florida Birding Festival and Nature Expo at the Harborview Center in Clearwater, Florida.

The Expo will offer field trips, exhibitions, demonstrations, and lectures. Take an expedition through Pinellas County's newest park, Wall Springs. And an evening walk on the beach under the stars will be a remarkable nature experience as guests learn about tidal influences and discover the birds, crustaceans, and other creatures that make the beach home. An impressive lineup of keynote speakers includes Dr. Jerry Jackson, who will present "John James Audubon – His Art and Science;" Arthur Morris, who will teach the "Art of Bird Photography;" and Paul Konrad, who will host "Favorite Birding Hotspots."

In addition to promoting the natural beauty of Florida, the festival's goal is to expand conservation and environmental management efforts throughout the Tampa Bay area. To support this effort, proceeds from the festival will benefit the Pinellas County Environmental Foundation (PCEF).

Plus Eagle Optics will feature some of the newest equipment available to make your nature experiences even better. From optics, outdoor gear, and apparel for birding, butterfly watching, and hiking, Eagle Optics is an expert.

Located on the Atlantic Flyway, off the Georgia coast, Little St. Simons Island is a favorite fall migration spot. Make sure to bring your binoculars, camera, and plenty of film. You can see red knots, dunlins, and sandpipers as they rest and forage for food on the beaches, using the untouched island habitat as a safe haven during their journey south.

Little St. Simons Island is a privately owned 10,000-acre barrier island. Accessible only by boat and allowing just 30 overnight guests, The Lodge at Little St. Simons Island provides the perfect birding vacation.

alabama's gulf coast

The combination of an abundance of birds, access to birding sites, and the amenities and convenience of Gulf Shores and Orange Beach make Alabama's Gulf Coast an ideal destination for birders. The fall bird migration takes place from mid-September through mid-November and offers some of the most exciting migratory bird watching in the country.

One of your stops on the Alabama Coast should be the Bird Banding Station at Fort Morgan State Park. This fall's bird banding will take place from October 6th through the 18th. The Hummingbird Study Group captures and bands hummingbirds and other Neotropical migrants at this historic location, which is the last departure point for thousands of migrating birds before they journey across the Gulf of Mexico. Banding sessions at the Fort Morgan Bird Banding Station are open to the general public. There is an admission fee to get into the fort, but the banding sessions are free.

Before you head down south, call the Alabama Gulf Coast Convention & Visitors Bureau for a copy of the Alabama Coastal Birding Trail brochure, a 51-page booklet, complete with maps and full-color photographs, that introduces visitors to the trail. The brochure gives directions to the area's most-frequented birding spots and lists the indigenous Alabama birds and migratory Neotropical songbirds that might be observed in the different habitats around the Gulf Coast.

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This year, Swift introduced the Swift 829 Warbler, a newly designed waterproof binocular that weighs only 20 ounces. Specifically designed with a bird watcher in mind, this binocular has a textured rubber-armored covering that helps to keep it quiet, absorb shock, and makes it easy to grip and hold onto. Its multicoated optics resolve images with tremendous clarity and high definition. The perfect traveling companion, this binocular can be worn all day hiking on the trail or cruising along the coastline without causing neck fatigue.

September and October are the perfect months to witness Norway's bird migration across the North Sea. If hiking isn't your cup of tea, take a journey to the heart of Norway on a Norwegian Coastal Voyage. This unique fleet carries passengers, mail, and supplies to over 30 ports, most never visited by cruise liners. Choose between three distinct vessel types in the 11-strong Norwegian registered fleet, with departures every day of the year. Follow the stunning coastline from the temperate climate of Bergen in the south to the dramatic fjords in the Land of the Midnight Sun near the Russian border. The long Norwegian coast is home to millions of seabirds, including a large number of auks and kittiwakes, which are found in the northern half of the country.

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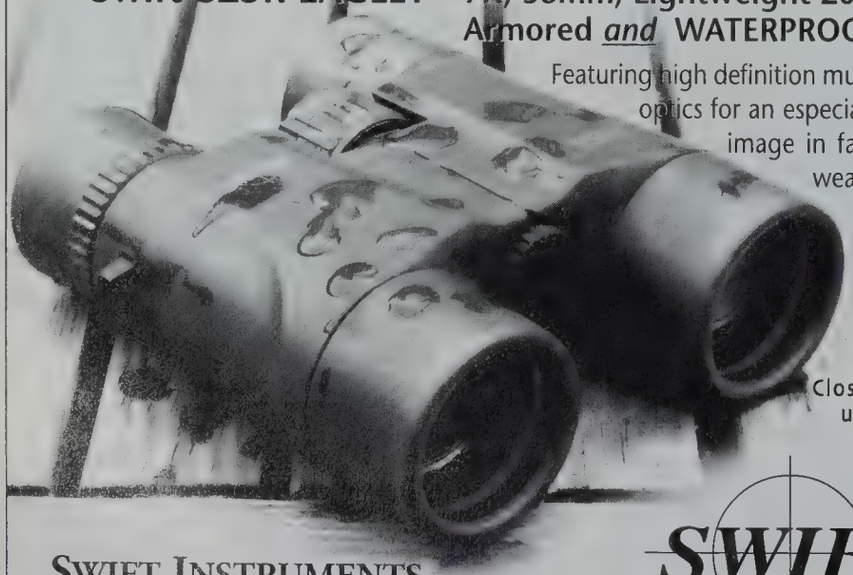

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maryland birding

In the fall, sparrows, warblers, and yellow throats all stop in Maryland on their annual migration south. Visit Charles County to take advantage of a dense population of nesting bald eagles, acres of beautiful forestland, and 150 miles of spectacular shoreline. The county is bordered on the east and south by the Potomac River, on the west by the Wicomico River, and on the north by the Mattawoman Creek. The habitat includes many large and small lakes, ponds, and extensive wetlands.

Chicamuxen Wildlife Management Area abounds with a wide variety of waterfowl species. Check your field guide to identify gadwalls, widgeons, wood ducks, hooded mergansers, ringnecks, and maybe a scalup or a canvasback. Also, adult and immature bald eagles can be seen almost daily hunting the marshes and upland areas.

Birding in Worcester County offers a remarkable unspoiled wilderness that attracts, sustains, and protects much natural life. Within a radius of just a few miles exist the unique–yet easily accessible–worlds of a barrier island, a cypress swamp, centuries-old forest, tidal wetlands, and secluded fields. Stop along the coast in Assateague and view innumerable migratory species, including peregrine falcons, merlins, and enormous flocks of tree swallows continuing their flight south.

For More Information

Places to Go

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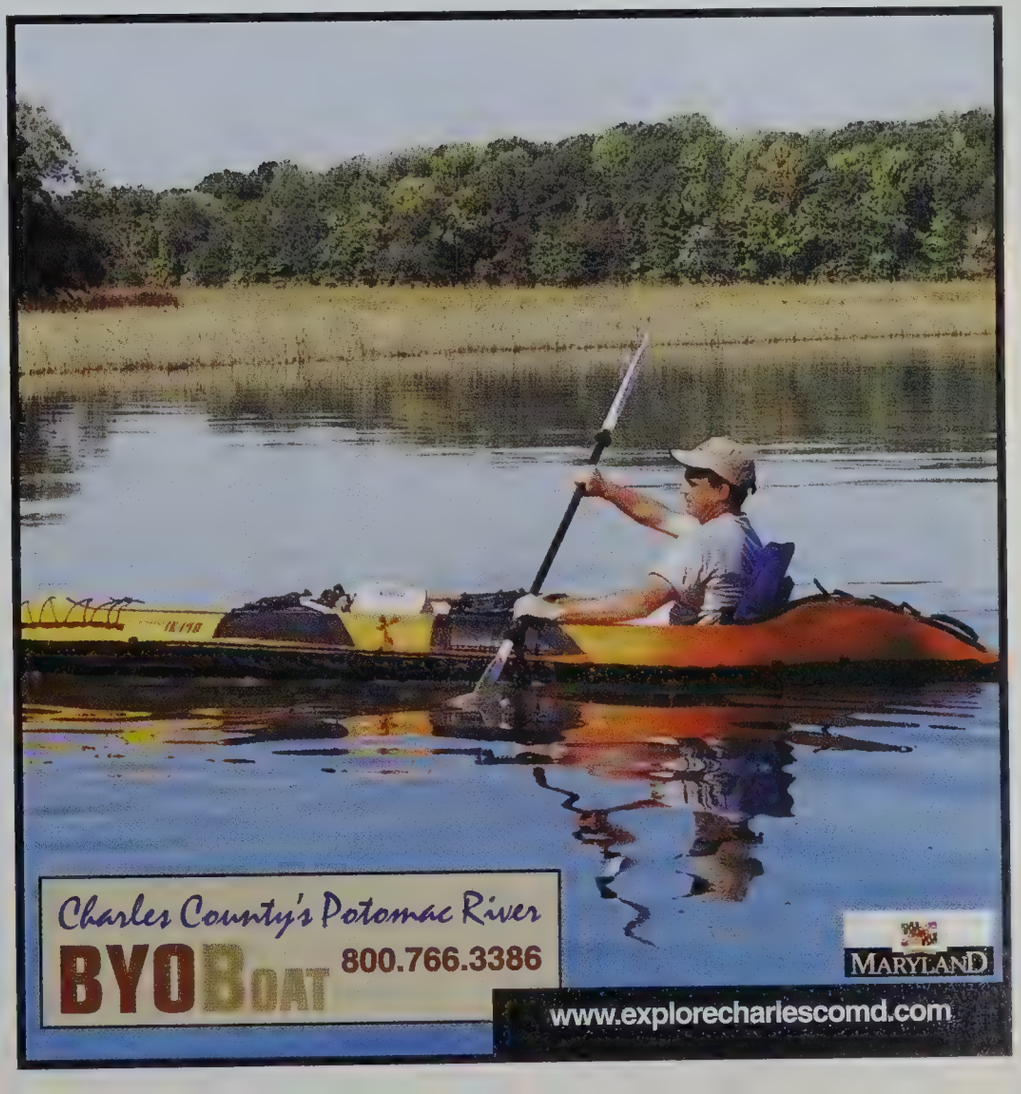

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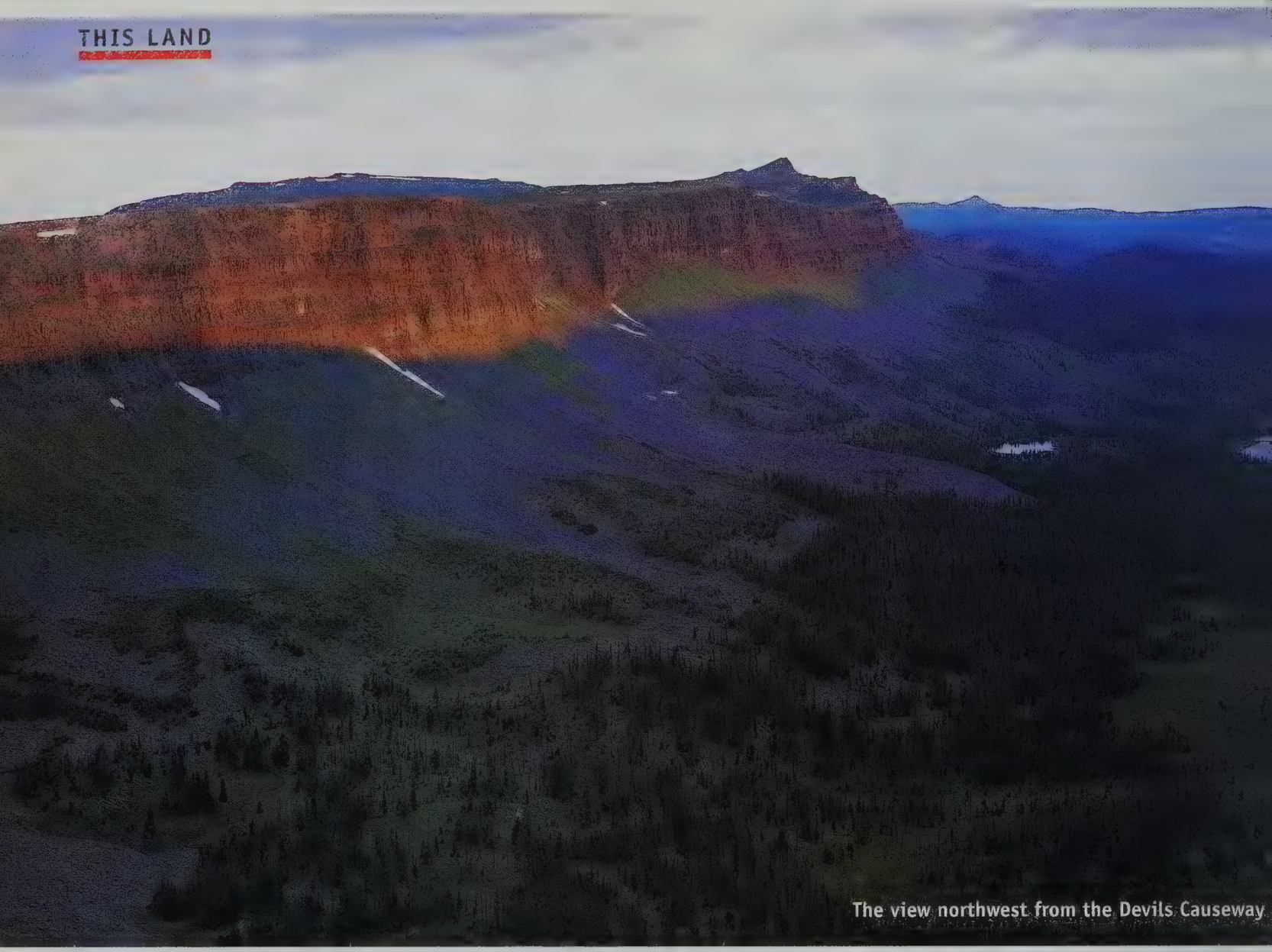


The view northwest from the Devils Causeway

Colorado's Flat Tops

Lava, glaciers, wind, and water have left a legacy of eye-catching mountains.

By Robert H. Mohlenbrock

In northwestern Colorado, within the great Rocky Mountain range, is a mass of blunt-topped mountains known as the Flat Tops. Rising roughly 9,000 to 12,000 feet above sea level, they have been carved out at the eastern edge of a large plateau by the action of wind, water, and Ice Age glaciers. The patterns of erosion are striking, in part because underlying layers of sedimentary rocks (sandstone, limestone, shale) are capped by a harder layer of basalt, a volcanic rock. Some of the mountains have amphitheater-like shapes that almost appear to be the work of giants.

Flowing westward across the plateau from the Flat Tops is the White River, a tributary of the Colorado. It passes through rolling grasslands and, in less arid areas (generally on north- or east-facing slopes and along streams), through stands of forest. Above the timberline, which lies at about 10,200 feet, the habitat is alpine tundra. From there down to about 8,100 feet is a subalpine forest with subalpine fir, mountain ash, and other species. Below this level grows montane forest, where the subalpine fir and mountain ash are virtually absent. A spruce bark beetle epidemic in the middle of the

twentieth century left behind many standing dead trees in the Flat Tops area, so it is often referred to as the Ghost Forest.

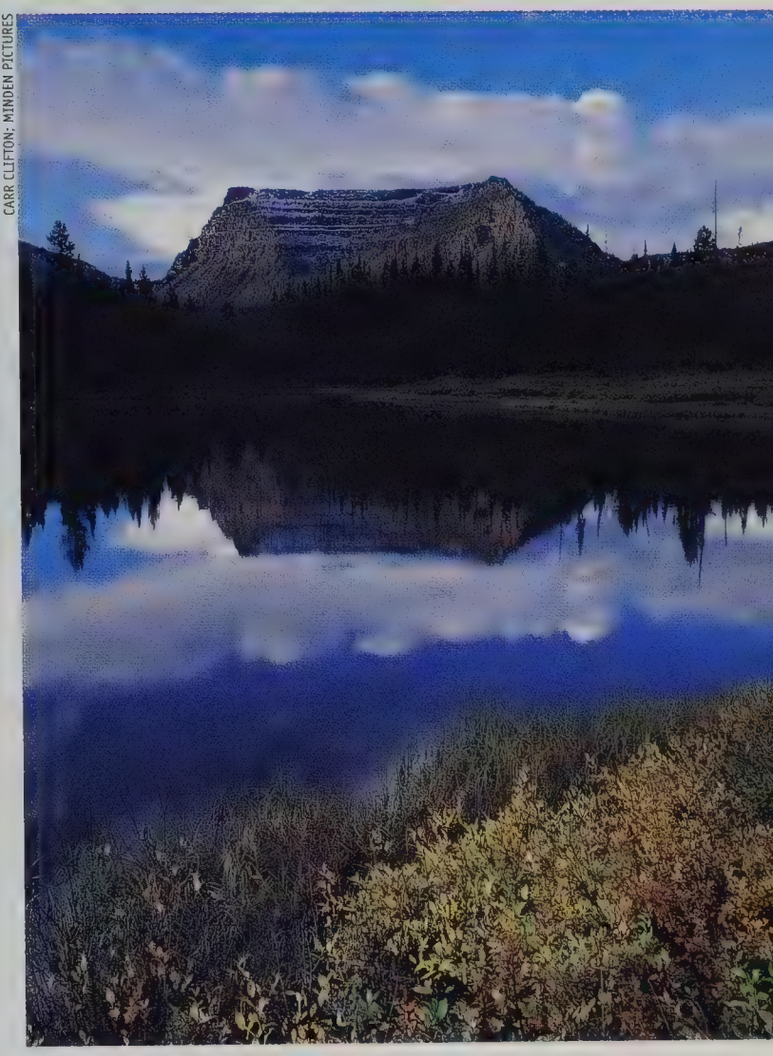
The Flat Tops fall within the Routt and the White River National Forests, where a nearly 370-square-mile section has been designated the Flat Tops Wilderness Area. This rugged zone is off-limits to motorized vehicles and equipment, but a scenic, mostly gravel highway meanders across the plateau for eighty-two miles, connecting Yampa and Phippsburg in the east to Meeker in the west. Taken westward, the highway first climbs to Dunckley Pass and, after following a roller-coaster course, tops out at 10,343 feet at Ripple Creek Pass. It then descends toward the North Fork of the White River. The main road continues downriver, but a turnoff can be followed upriver for about eight miles to Trappers Lake, near which are a campground and the Trappers Lake Lodge and Resort.

Trappers Lake, which lies within the wilderness area, was the first U.S. National Forest property to be treated as a wilderness—long before Congress passed the Wilderness Act of 1964. In 1919 the U.S. Forest Service hired a young landscape architect, Arthur H. Carhart, and told him to do a survey for a road around the lake and several homesites on the lakeshore. Carhart completed the task but urged his supervisor, Carl Stahl, to save the lake for wilderness recreation. Stahl backed the recommendation, and in 1920 Trappers Lake was declared an area to be kept free of roads and development. Carhart's vision remains a landmark in the history of wilderness preservation: "There is a limit to the number of lands of shoreline on the lakes; there is a limit to the number of lakes in existence; there is a limit to the mountainous areas of the world," he wrote in a memorandum. "There are portions of natural scenic beauty which are God-made, and . . . which of a right should be the property of all people."

Trappers Lake is nearly a mile and a half long and a little more than half a mile across at its widest point. Providing a formidable background on its northeast side is the so-called Chinese Wall, a sheer face that rises 1,650 feet. This basalt formation extends for nearly five miles in an irregular semicircle. Because of its sheerness and direct exposure to the afternoon sun, the side facing the lake is bare of vegetation except for some rock-hugging lichens.

The view of the Chinese Wall from below is rewarding enough, but adventuresome hikers can take various trails that provide a close-up experience. (Horses may also be hired at the lodge.) My wife, Beverly, and I took the Stillwater Trail, which heads east from Trappers Lake, passes Little Trappers Lake, and, after a sharp bend, comes face-to-face with the wall. At this point the trail climbs over the formation's south end, going from 10,000 feet to 11,000 feet in little more than a mile. After another mile, we turned onto the Chinese Wall Trail, which winds northward near the top of the mountain.

Two miles along this route, we came to a branch trail leading east to the Devils Causeway. This, we soon discovered, is a craggy ridge only four feet wide, with precipitous 1,500-foot drop-offs on both sides. The passage looked far too scary, so we retraced our steps and continued north. After a gentle descent, we reached the Lost Lakes Trail and headed back south to complete our round trip.



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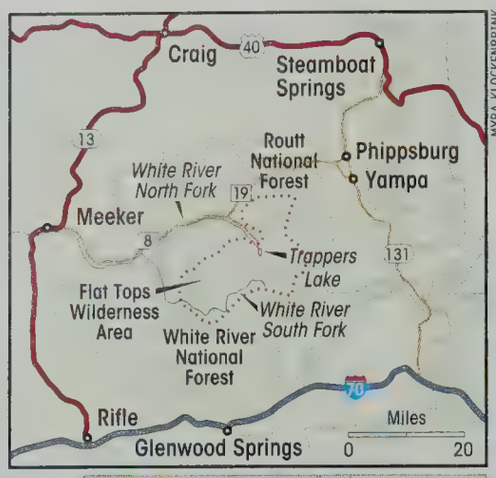
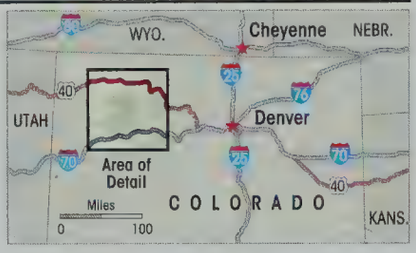
Top: The Chinese Wall viewed from Trappers Lake. Above: An aerial view shows the wall as a dark, shadowy edge beginning at bottom left.

Robert H. Mohlenbrock, professor emeritus of plant biology at Southern Illinois University, Carbondale, explores the biological and geological highlights of U.S. national forests and other parklands.



MYRA KLOCKENBRINK



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DENNIS FLAHERTY

ERIC WINBRAW

HABITATS

Grassy meadows often appear on flat terrain and on west- or south-facing slopes. Slender wheatgrass, nodding brome, fringed brome, oat grass, red fescue, June grass, and mountain muhly are the most abundant species in dry areas. Most of these flower beginning in July and continuing on into autumn. Where a more moist habitat is created by seeps, the grasses include redtop and meadow foxtail. Above 10,000 feet, Thurber's fescue and alpine timothy are common.

Roads that penetrate the Flat Tops have disturbed the native vegetation, permitting the invasion of European species such as orchard grass and timothy, along with opportunistic wildflowers such as milfoil (yarrow), oxeye daisy, fleabane, Indian paintbrush, and thistles.

Alpine tundra vegetation consists of dwarf willow trees about one foot tall, an abundance of sedges, and various deep-rooted, mat-forming wildflowers. Among these are nailwort, slender mountain sandwort, rock jasmine, and alpine primrose.

Subalpine forest has subalpine fir, Engelmann spruce, lodgepole pine, and mountain ash. Myrtle-leaved blueberry is the most abundant shrub, while a species of wild rose *(Rosa woodsii)* and Colorado currant are also common. Wildflowers include larkspurs, Colorado blue columbine (the state flower), several species of beard-tongue *(Penstemon)*, sweet cicely, Jacob's-ladder, and several kinds of *Arnica*—whose flower heads resemble those of daisies, except that they are entirely yellow or orange.

Montane forest has lodgepole pine and Engelmann spruce, with Douglas fir often found on north slopes and ponderosa pine on south slopes. Other trees include aspen and Rocky Mountain maple. The mixture of shrubs and wildflowers is similar to that in the subalpine zone, but wax currant grows here instead of Colorado currant.

Wetland habitat appears along the streams and around the ponds and lakes that dot the plateau. These areas are often lined with Geyer's willow, Wolf's willow, and narrowleaf cottonwood. Red elderberry, snowberry, and a species of prickly currant are common in the shrub zone. Among the wildflowers are a wild geranium, an aster *(Aster porteri)* with smooth stems and leaves, leafy arnica, yellow monkey flower, meadow rue, and bluebells. The scouring rush, a spore-bearing plant with jointed, leafless stems, is also common.

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CONSUELO DE MORAES AND ANDREI SOURAKOV

STAY AWAY FROM TOBACCO Scientists have long known that plants can send a strong message to hungry insects by releasing volatile, sniffable chemicals. Now a team of entomologists led by Consuelo De Moraes, of the USDA-ARS Center for Medical, Agricultural, and Veterinary Entomology in Gainesville, Florida, has found that not only does at least one plant—*Nicotiana tabacum*, the most common species of tobacco—emit volatile chemicals by day, it emits a different blend of chemicals by night. And this cyclical chemical production is closely linked to the life cycle of the plant's main nonhuman consumer, the tobacco budworm *(Heliothis virescens)*, whose adult stage is a nocturnal moth.

The newly discovered nighttime blend of volatile compounds released by *N. tabacum* can be detected by receptors on the moth's antennae; the female moth interprets the compounds as a warning that the plant is saturated with competitive insect larvae or that it is of low nutritional value. Either way, she tends to get the message and go elsewhere to lay her eggs.

If, however, a moth manages to lay eggs on *N. tabacum*'s leaves, and caterpillars emerging from those eggs feast on the leaves in the light of day, the caterpillars' saliva is drawn into the plant's vasculature. There it stimulates the production of daytime-only compounds. These attract the tobacco budworm's natural predators, which follow the wafting chemicals to the infected plant and dine on the caterpillars. The researchers are now exploring whether the moths are "making sophisticated choices based on the likely presence of particular larval competitors and perhaps even of particular predators and parasitoids." ("Caterpillar-Induced Nocturnal Plant Volatiles Repel Conspecific Females" and "Night Moves of Pregnant Moths," *Nature* 410, 2001)—*Heather Van Doren*

SHARK TALES Surprisingly little has been known about how the great white shark *(Carcharodon carcharias)* goes about its daily business. But new genetic research shows that in some ways, the great white behaves more like a marine mammal than like other fish.

Zoologist Amanda T. Pardini, of the University of Aberdeen in Scotland, and colleagues examined mitochondrial DNA (which is inherited only from the mother), as well as DNA inherited from both parents, in great whites in South African, New Zealand, and Australian waters.

MIKE PARRY; MINDEN PICTURES

Analysis of the mitochondrial DNA showed that the sharks from Australia and New Zealand constitute a single population, genetically different from the South African sharks. But when the researchers tested the bi-parentally inherited DNA, they found *no* significant genetic differences between the two groups. These apparently contradictory results suggest that female great whites seldom stray from their native territories and so never have an opportunity to pass on their mitochondrial DNA to other populations, whereas males go much farther afield and contribute genes to different populations, negating local differences that arise in the bi-parentally inherited genome. A disparity between the home ranges of males and females is also commonly found in marine mammals such as whales and dolphins. ("Sex-Biased Dispersal of Great White Sharks," *Nature* 412, 2001)—*Kirsten L. Weir*

EXPANSIVE INSECTS Climate warming has increased the amount of suitable breeding ground available to a few fortunate insects whose need for warmth used to confine them to scattered tepid areas. According to C. D. Thomas, of the University of Leeds, and colleagues, the silver-spotted skipper *(Hesperia comma)*, a butterfly previously restricted to south- and southwest-facing chalk grassland fragments in southeastern England, now roams a wider territory, encompassing east-, west-, and north-facing hillsides as well. Since 1982, the area hospitable to the butterfly has doubled, the distances between the separate patches of hospitable land have decreased, and *H. comma* populations have begun to generate emigrants. As a result, the butterfly's geographic range has tripled.

Another butterfly that has expanded its horizons is the brown argus *(Aricia agrestis)* in central England. Historically, in the southern parts of its range, its host plants were primarily *Geranium* species. In the northern, cooler parts, it favored *Helianthemum chamaecistus*, a plant that grows on sheltered or south-facing hillsides, which are likely to be warmer than most *Geranium* habitats. During the past twenty years, however, the brown argus has been spreading its wings—mostly northward into *Geranium*-rich areas. Why is the butterfly lighting on northern geraniums that previously it did not bother with? Answer: climate. In the 1980s and 1990s, the northern *Geranium* habitats warmed. Not only has the brown argus moved into those habitats, it's been using them as stepping-stones to populations of *H. chamaecistus* that used to be too far apart.

The researchers also found that two species of bush crickets have prospered. Formerly restricted to southern coastal areas of England, the long-winged cone-head *(Conocephalus discolor)* and the flying form of Roesel's bush cricket *(Metrioptera roeselii)* have begun to spread northward and inland. ("Ecological and Evolutionary Processes at Expanding Range Margins," *Nature* 411, 2001)—*Kate Hamill*

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ENGINEERING THE APPLE

By Sue Hubbell

Adapted from *Shrinking the Cat: Genetic Engineering Before We Knew About Genes*, by Sue Hubbell. Copyright © 2001 by Sue Hubbell. Published by Houghton Mifflin and reprinted by permission.

Braeburn apple, Wenatchee, Washington

Eating apples were first harvested millennia ago in central Asia. Humans have been tinkering with the fruit ever since.

One autumn morning not long ago, I was walking down a row of espaliered apple trees near Geneva, New York. I was visiting the biggest living library of apple trees anywhere in the world—the Plant Genetic Resources Unit of the U.S. Department of Agriculture (USDA), based at Cornell University. The day was cold and the sky leaden, promising an early snow, but maples in full autumn color ringed the field and echoed the cheerful reds, russets, and yellows of the apples. Some of the apple trees had drooping limbs; some grew straight and stiff. The shape of the leaves and the color of the bark varied, as did the fruit—some in clusters, some dangling independently. Some apples were huge, others not even bite-sized. The names of some apples were unfamiliar to me, yet they tasted so good that I wondered why they weren't in markets. Others were so sour or bad-tasting that I quickly understood what apple growers mean by the word "spitters." The trees—and the look and taste of the fruit they bore—were so dissimilar that it was hard to believe the entire group was botanically related. But my guide for the morning, Philip Forsline, curator of apples and sour cherries for the USDA, told me that even bad-tasting ones could be of interest because of their manner of growth, time of bearing, hardiness, or resistance to disease and pests.

A Roman mosaic, below, shows farmers grafting apple trees. Opposite page: The harvest at an organic orchard in Washington State.

ERICH LESSING/ART RESOURCE

Commercial apples are a serious business in the United States, the world's second-largest apple-producing country (after China). Putting in a commercial orchard or replanting an old one with a new variety takes money, time, and labor. Years pass before new trees bear enough fruit to pay back the orchardist for the investment, so apple developers need to be sure of the qualities being packed into a new variety before they promote it. And this is where apples present a real challenge. Nearly every apple tree grown from a seed is a new variety, whose fruit may not be at all like that of the mother tree. Such unpredictability is a serious problem for orchardists. Their most common solution—invented long before there was a sheep named Dolly—has been a type of cloning known as grafting, an ingenious way that humankind discovered to make an end run around the intricacies of apple genetics. Orchardists take a shoot (called a scion) from a tree that bears good eating apples and bind the shoot to the trunk of a tree that doesn't produce good apples but has other desirable properties, such as vigor, resistance to disease, or the ability to stay a manageable size. The grafted shoot will grow up to produce the same good apples as the tree it was taken from. It is a clone of that tree, growing on another root system.

A hands-on solution to a practical problem, grafting offers little insight into apple genetics, which are so complex that bewildered botanists used to think that apples did not obey Mendel's laws. It is true that the progeny grown from the

TROUT
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FRONTISPIECE FOR JOHN MILTON'S *COMUS*; ILLUSTRATION BY ARTHUR RACKHAM. MARY EVANS PICTURE LIBRARY

seeds of an apple tree do not sort themselves out into the neat, predictable pattern that Gregor Mendel first laid out in the 1860s with his pea plants. But we now know that Mendel was lucky. The pea plant traits he studied (flower color, for instance) are controlled by single genes (or "factors" of inheritance, as he called them). More often, though, a single trait is affected by more than one gene. In addition, certain genes are expressed only

Apple growers have benefited from the fruit's easygoing acceptance of extra chromosomes.

when environmental conditions activate them (such as the darkening of Siamese kittens' paws due to the lower temperature of their extremities). And that's just for starters.

Like cats and people, most apple trees are diploid—that is, their genes occur on pairs of chromosomes. Typically, apples have seventeen pairs of chromosomes, for a total of thirty-four. But some varieties are haploid, with seventeen *single* chromosomes. Others, especially among crab apples, are polyploid, which means that their chromosomes are not paired but tripled, quadrupled, quintupled, or even wadded up into bundles of six. In fact, some apples have as many as eighty-five chromosomes. And each of the genes on each of the chromosomes can have different alleles (alternative forms). A single seed may thus contain a lot of genetic variation that has accumulated down through the ancestral lines.

Orchardists have unquestionably benefited from the apple's easygoing acceptance of extra chromosomes. Many familiar varieties of apples are polyploid: Stayman, Jonagold, Baldwin, and the beloved old pie apple Rhode Island Greening. The Jonagold is a modern, contrived cross between Jonathan and Golden Delicious parents. But the Stayman sprang up all on its own, from a Winesap seedling in Kansas; the Baldwin and Rhode Island Greening, too, were spontaneous polyploids.

The desire for a predictable product, however, has led most growers to focus on a very limited portion of the apple's tremendous genetic diversity. In fact, the vast majority of contemporary apples are the progeny of just a few varieties—a dozen at best. As a result, today's available genetic base is meager compared with that in the nineteenth century, when an estimated 7,000 or more kinds of apples were cultivated. In addition, many of the varieties commercially grown today "present well" (that is, have a uniform, unblemished appearance), but they no longer have much flavor. This is why many horticulturists have recently been devoting themselves to tracking down old varieties on abandoned farms and in old cow pastures. And it is why, since 1989, the USDA has been sending scientists on collecting expeditions to the presumed birthplace of eating apples: the high-altitude forests of Kazakhstan, in central Asia.

The apple brought back to the Cornell facility from Kazakhstan is *Malus sieversii,* a tree with no common name. Many researchers, including Philip Forsline, believe that *M. sieversii* is the principal ancestor of all the varieties of apples we buy at the supermarket, which are collectively known as *M.* x *domestica.* The *M. sieversii* seeds gathered during the first expedition to this species' homeland—in the region of the Kazakhstani industrial town of Almaty (formerly Alma-Ata, "father of apples")—have produced trees that are now mature enough to bear apples. Trees at the facility are grown in tight, close rows, which keeps them more compact and uniform than they would be in their native forests. Nevertheless, even to an untrained eye the individual trees show obvious differences. The leaves are of various shapes and hues; the trees branch and twig in different ways. Some send up many stems, giving the trees a shrubby appearance.

ERICH LESSING/ART RESOURCE

Legendary apples, opposite page: The Hesperides guard a tree bearing the golden apples given to Hera as a wedding present. Below: *Temptation of Eve,* by the sculptor Gislebertus, ca. 1130.

Also in the USDA collection are younger *M. sieversii* trees, grown from seeds gathered more recently and a long way from Almaty, in places that have never been farmed. Too young to bear fruit, these trees are still thorny, betraying their relationship to roses. (Roses and apples belong to the large family Rosaceae, which also includes strawberries,

JOHN MARSHALL

Ready for the harvest: Three-year-old Gala apple trees in a commercial orchard, right. Below: Grafting involves inserting and sealing "scion wood" into slits in a tree's trunk.

JOHN MARSHALL

pears, and the stone fruits, such as plums, cherries, and apricots.) Some of the new seedlings are already showing resistance to various pests and diseases. According to Forsline, "The interesting thing is that since the trees in the apple forests grow up from seeds, each is different from its neighbor. You can see a healthy tree growing right next to a diseased one. Resistance is genetic. We think it would be good if we can incorporate resistance into commercial varieties of apples."

Apples of the species *M. sieversii* were first described in modern times by P. S. Pallas, a German naturalist who in 1786 saw them growing in the Caucasus, where, he noted, apple trees competed for dominance with oaks. In 1911 Frank Meyer, an American who traveled the world looking for unusual plants, took note of the apple forests in the Tien Shan ("mountains of heaven"), a range straddling the border where China meets Kazakhstan and Kyrgyzstan. Meyer had crossed into those mountains from China in early spring and had spent the next few months exploring the range, struck by the unusual forests of apples he found, sometimes at altitudes of 10,000 feet. No one followed up on his discovery until the 1920s, when Russian agronomists started investigating the area.

People who think the apple originated in Kazakhstan theorize that *M. sieversii* probably hybridized rapidly with crab apples native to central Asia. According to some botanists, it is those hybrids, not pure *M. sieversii,* that became the ancestors of what we now think of as proper eating apples. But others disagree, seeing the wide distribution of crab apples—which are native not only to Asia but to northern latitudes around the world—as evidence for apples having had other places of origin. Through genetic change, crab apples might, on their own, have come to produce apples that were sweeter and bigger—the ancestors of domestic apples.

The question of whether apples began in one place or several may now have been settled by Barrie Juniper and other scientists at the University of Oxford, who have been analyzing the chloroplast and nuclear-DNA sequences of cultivated apples in order to untangle their origins. Their work to date has uncovered no evidence that *M. sieversii* hybridized as it moved westward—supporting the claim that the wild apple forests of Kazakhstan did indeed give rise to the sweet eating apple.

Grafting was humankind's way of making an end run around the complexities of apple genetics.

Wherever apples originated, by the middle of the third millennium B.C., tasty eating apples were being cultivated far to the west of the Tien Shan range, even as far as Persia. By the first millennium B.C., apples had become a standard part of the diet of the well-to-do in the Mediterranean world. The Romans spread the knowledge of apples and their cultivation throughout the territories they conquered. By medieval times, orchardists in Europe had become so skilled that the privileged classes could offer apples to their guests every month of the year by growing some varieties that ripened early and others that were "good keepers," retaining their freshness through the winter. To own an apple orchard was as much a source of pride as having a good wine cellar is today.

ELIZABETH DICKSON

Yet apples were not universally admired during the Middle Ages, especially among the less privileged. Popular wisdom had it that apples caused "bad stomachs" and fever, as well as "ill humors." This belief may well have been reinforced by the apple's association with the Fall in various translations of the Bible, including the King James Version (though in the oldest Hebrew and Greek texts, the Tree of Knowledge bears merely a generalized "fruit").

For several hundred years, apples were treated with some suspicion, but by the seventeenth century the fruit was back in favor, and many varieties were being grown and grafted throughout Europe. Settlers in the New World, finding the place lacking in sweet apples, were quick to import them from Europe. New Englanders grew apples not so much for eating as for animal feed and cider making. (At the time, access to potable water was not a simple matter of turning on the tap, and the newcomers needed to produce a beverage that would satisfy thirst without making them ill. Cider, fresh or hard, was such a drink.) For these purposes, good eating apples were not necessary. In addition, the first settlers—often urban dwellers unskilled in rural crafts—may simply have been ignorant of grafting.

Above: Apple specialist Philip Forsline in a Kazakhstani forest of *Malus sieversii*. Map: The town of Almaty is known as the "father of apples."

For whatever reasons, most apple trees in America grew for a couple of centuries without benefit of grafts. And without grafting to produce only selected strains, the rich genetic heritage locked up inside the wild apple trees was allowed expression—serving as what one collector of wild apple seedlings called "the biggest genetic experiment the planet has ever seen." This genetic experiment was taken westward by John Chapman, better known to generations of Americans as Johnny Appleseed, who traveled more than 100,000 miles across the Midwest, handing out and planting apple seeds along the way. Since he was a follower of Emanuel Swedenborg, an eighteenth-century Swedish scientist and religious thinker who con-

demned tampering with the will of nature, Chapman eschewed grafting.

By the time of Johnny Appleseed's death in 1845, however, grafting was becoming the preferred method of propagation for serious commercial orchardists in the United States, as had long been the case in Europe. Greater control over apple production led to a growing emphasis on the appearance, shipping, and keeping qualities of apples rather than on their flavor. And by limiting the genetic base of the apples they grew, orchardists increasingly found the fruit susceptible to scab, mildew, brown rot, and a host of other diseases—not to mention coddling moths, aphids, and spider mites, three of the hundreds of insects and mites that plague the modern grower. Nowadays those diseases and pests are fought with a whole witches' brew of chemical sprays, dusts, and powders—which gets us back to the USDA's interest in the apples from Kazakhstan, many of which show innate resistance to bugs and blights.

When resistance comes from several genes—that is, when it is polygenic—it is longer lasting, but such resistance is harder to achieve in crossbreeding. Single-gene crossbreeding for resistance can be done by first making the original cross and then backcrossing to eliminate traits such as small size and sour taste that may have come along with the desired gene. But when the trait is polygenic, it may take five or six backcrosses to eliminate the unwanted genes that have hitchhiked along with those helping to confer resistance. One apple tree generation is about four years (that's how long it takes, on average, before a tree bears fruit), so the development of polygenic resistance would take something like twenty years, as well as a plot of land big enough to grow and try out many crossbred trees.

ERICH LESSING/ART RESOURCE

Isaac Newton's tree-shaded worktable, below. Did a falling apple inspire his concept of gravity? Opposite page: Fluctuating summer weather resulted in three stages of bloom at one time for a Braeburn apple.

This explains why many apple breeders are interested in genetic engineering—in the new sense of what is called transformation. If the genes responsible for a certain trait can be identified and directly transferred, the process of transformation is quick, efficient, and in some ways easier than crossbreeding, because it eliminates the need for backcrossing. Resistance can even be transferred from animal species. The cecropia moth, for example, produces a peptide that attacks many kinds of bacteria. When the moth gene responsible for producing that protein was added to the DNA of apples used for rootstocks, the apples grafted onto them

Apples from Kazakhstan don't need a whole witches' brew of chemical sprays, dusts, and powders to fight off bugs and blights.

became resistant to fire blight, a devastating bacterial disease that turns apples, pears, and other plants black. And at least for Gala and McIntosh apples, the same cecropia moth gene seems to help confer scab resistance, too.

Whatever the promise (or, in the opinion of some, the threat) of genetic engineering, everyone agrees that preserving the natural diversity of apple trees should be a high priority. And on this score, there is cause for alarm: the apple forests of Kazakhstan are in danger of disappearing. "During the Soviet period," says Forsline, "the area was held as national parkland, but with the breakup of the Soviet Union, the mountains are no longer protected. Wealthy people are having many remote areas bulldozed and cleared in order to build vacation homes. The apple forests are disappearing, and the groves nearest to Almaty are 90 percent gone."

At the end of my tour through the Geneva orchards, I asked Forsline which apples would continue to grow if humans disappeared from the planet. He reflected for a moment and said, "Well, the eating apples that we've grown on this continent would soon be gone. Those need our care, and besides, they aren't native here. I don't think any of them would survive here." He paused, then added, "But apples would still grow in central Asia, and they'd be better."

In what way? I asked.

"The places where they grow now would no longer be threatened by development, and they would continue to evolve, growing hardier, more resistant to disease and pests, and better fitted to their particular surroundings." □

Sea Hunters of Lamalera

In an Indonesian coastal village, boatbuilders and whalers follow ancient rules.

Story and photographs by Fred Bruemmer

Above: In a painting on the prow of a Lamaleran boat, the snake symbolizes the tidal wave that destroyed the villagers' ancestral home. From his narrow platform on the bow, top right, a harpooner is ready to strike. Below right: Boats leave Lamalera at dawn with their palm-leaf sails unfurled.

Their boats are sacred and, they believe, immortal. Their prey is gigantic and dangerous. They are the sea hunters of Lamalera, an isolated village on the tiny Indonesian island of Lembata, 1,200 miles due east of Jakarta.

To the 150 or so hunters and the rest of the village's 2,000 people, each of the fifteen boats that operate out of Lamalera (formerly known as Lomblen) is a living being that links them to their ancestors and their ancestral home. That home, as legend has it, was to the north, on an island destroyed centuries ago by a tidal wave. After a long journey, two boatloads of survivors landed on the harsh, volcanic coast of Lembata, where they built a village above a crescent beach facing the turbulent but rich Sawu Sea. One of the two boats that brought their ancestors to Lamalera was, say the villagers, the *Kebako Pukã.*

In Lamalera I often traveled in a boat also called the *Kebako Pukã,* which, according to its crew, was identical in every detail to the original (the model for subsequent boats). When a boat dies—in a storm, of old age, smashed by a furious whale—the villagers mourn for two months while a replacement is built. It takes eighteen trees to build one. Root ends are used to make the stern, so that their life force will flow toward the head of the boat. Planks are carefully adzed—never bent—to the correct curve. The planks are caulked with palm-fiber oakum. Hand-carved wooden pegs—never nails, screws, or anything else metal—are driven in with stone hammers. Carved crosspieces are lashed to the frame with rattan. Finally a sacred symbol is painted on the prow; a common one is eyes that search unceasingly for prey. On the prow of the *Kebako Pukã* a snake coils around a mountain, symbolizing the tidal wave that destroyed the Lamaleran's ancestral home.

The boats are made by *ata molã,* highly skilled craftsmen from the village's nineteen boatbuilding clans. Robert Barnes, professor of social anthropol-

ogy at the University of Oxford and an expert on Lamalera's history and customs, has noted that the term *ata molã* is also used to refer to a priest.

The finished boat is heavy and sturdy. Thirty feet long, six feet wide in the beam, tapered at both bow and stern, it has a false keel of softwood that can easily be replaced if damaged in rough landings, a frequent occurrence. Its huge rectangular sail is woven from the leaves of gebang palm and suspended from a twenty-five-foot-high bipod bamboo mast. Two outriggers give the vessel great stability. Beyond the bow juts a narrow, five-foot-long, bamboo-and-plank platform. This is the precarious place from which the boat's single har-

pooner will launch his *kāfés*, harpoons at the tip of ten-foot poles.

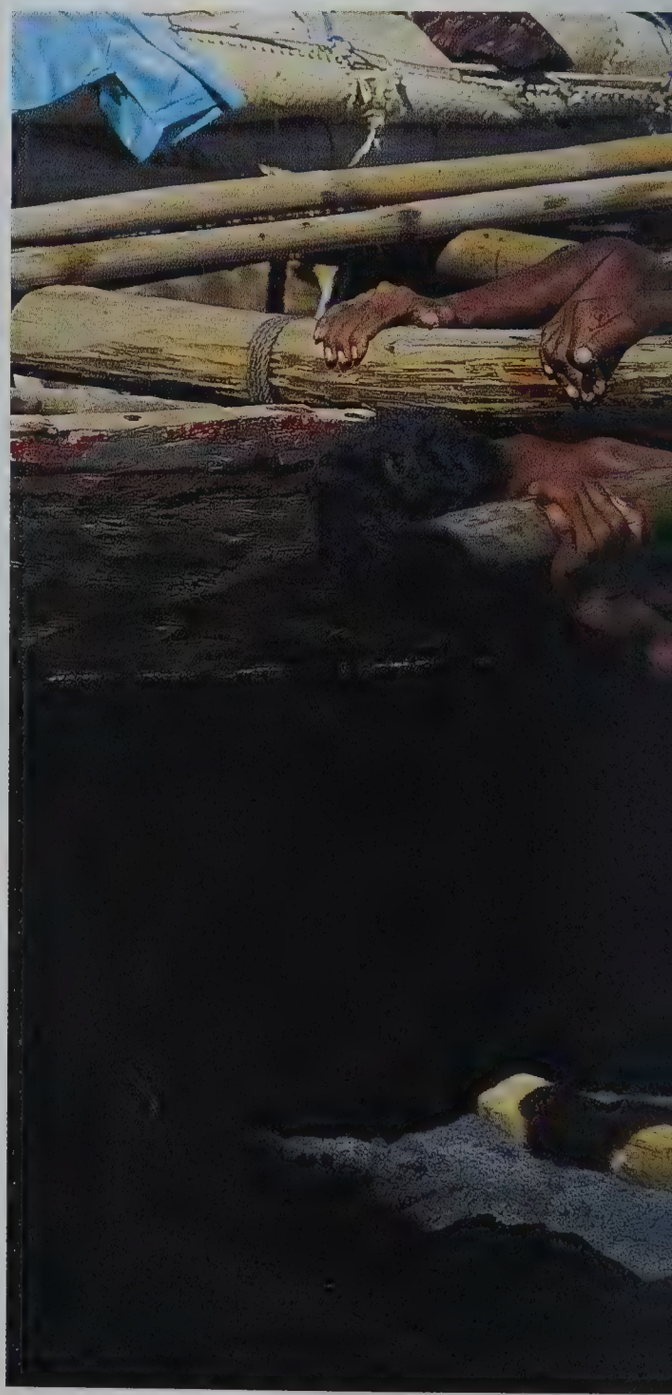
In Lamalera, animistic beliefs in the sanctity and spirituality of hunted animals exist in syncretic harmony with devout Catholicism. (Jesuit missionaries began visiting the village in the 1800s, and a permanent Catholic mission was established there in 1913.) Custom and conduct are governed by an ancient oral code. With little agriculture—villagers grow some corn and manioc—and no other industry, it is hardly surprising that the hunt is the center of life. Each May, after the priest has blessed the fleet and prayers have been offered to Kotekema, the spirit of the sperm whale, the hunting season begins. It will last until October.

Oil (for cooking and for lighting) is rendered from whale blubber, above. Right: Villagers drag a pilot whale to shore.

Lamalerans hunt several species of whales, the most feared, most respected, most sought after of which is the sperm whale. The annual catches peaked at fifty-six in 1969. But then, say the villagers, they sold one of the sacred sperm whale skulls lining the beach to tourists from a passing ship. This offended the whale's spirit, and for years afterward, no more than ten sperm whales a year were harvested. Catches have increased since 1990, however.

Today the sea hunters take mostly young male sperm whales, twenty to forty feet long, which eat the abundant Sawu Sea squid. Crews are leery of the full-grown sperm whale bull (up to sixty feet in length), a rarer sight. In 1994 two Lamaleran boats sank after being struck by a whale that had towed them for miles, almost to the island of Timor. A third boat picked up the crews and drifted for days until it was rescued by a passing ship.

Rejecting spinner dolphins (too fast) and baleen whales (taboo), Lamalerans hunt several species of sharks, including the great white but most often the large and lethargic whale shark (known to them as the stupid fish). They also go after sunfish, marlin, and dorado, as well as manta rays (the largest of all the rays, these can weigh up to one and a half tons). The hunt is hard work. The crews are out all day beneath the burning sun—and often return with nothing to show for their day at sea. They rarely eat or drink on board, so I learned to fill myself with



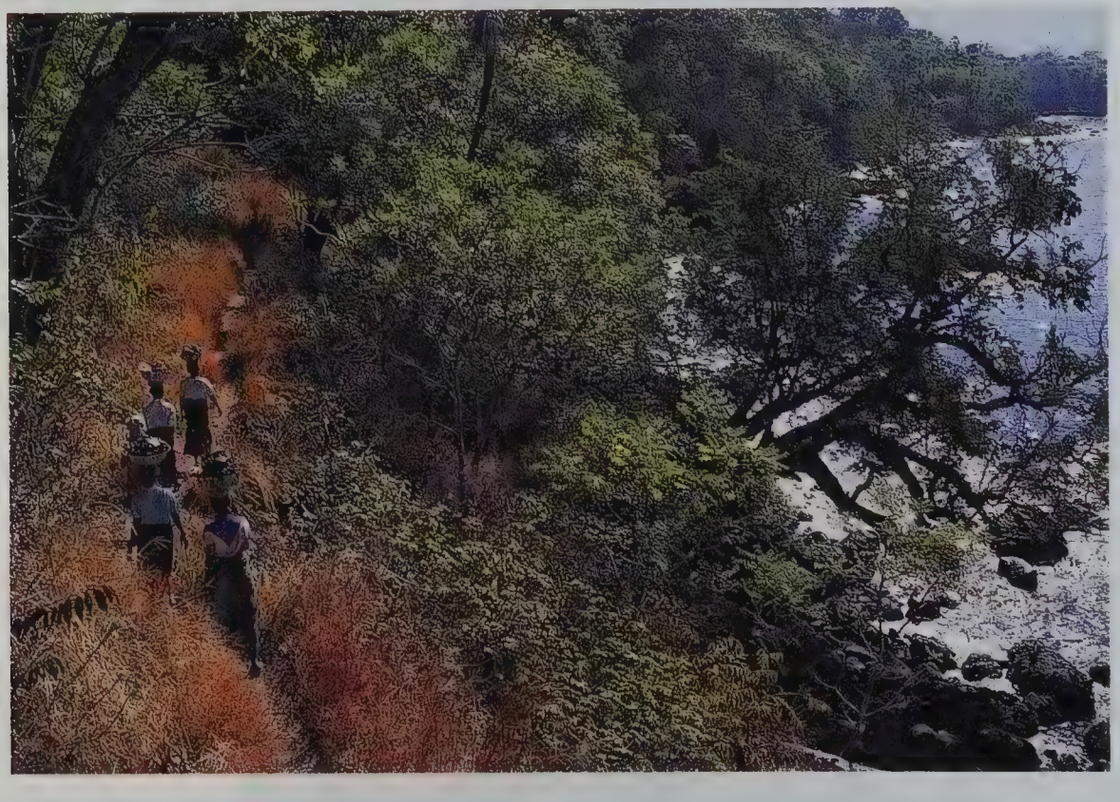
liquids, camel-like, before going out with them.

Weather permitting, the fleet sails at dawn every day except Sunday. On a slipway of hardwood logs, the heavy boat is slid from its palm-leaf-thatched shelter at the back of the beach down to the lethal-looking, pounding surf where the crew calmly waits for the highest wave. With one mighty shove from them, the boat rides out. The men quickly slide aboard, otter-smooth. They pole out beyond the breakers, settle on the thwarts, then row with all their strength to an ancient rhythmic chant, *"Hilabé, hilabé, héla, héla/hilabé, héla, héla. . . ."* Farther out, the chant changes into a song that translates as "We are the men from Lamalera/We are the hunters of the whale."

The boats have false softwood keels that can easily be replaced if damaged in rough landings.

Suddenly, a few miles from shore, they stop while the harpooner sharpens his *kāfés*. The men remove their hats and pray, first a paternoster in Lamaholot (the language of Lamalera, Lamaholot is one of many languages of eastern Indonesia), then a final plea: "Lord bless our hunt and let us return alive." With this ritual, the hunt becomes holy. The mast is raised, the great golden sail is unfurled, and the boat sails farther out into the Sawu Sea—often up to eight miles. There the

The heavy boats are thirty feet long and six feet wide. It takes many hands to haul a boat from the sea.



Lamaleran women, above, carry meat and fat to a market five miles away. They barter for fruit, vegetables, rice, and maize with women from mountain villages, top.

crew tacks and jibes, ever alert for the telltale spout of a distant whale, the curled tip of a manta ray's wing, the sheen of a shark near the surface.

Out there, with nothing to distract from the lazy roll of oily swells, the boat's dull creaking, the faint flapping of the sail, the burning sun, I learned what Samuel Taylor Coleridge meant by "As idle as a painted ship/Upon a painted ocean." Then, at a sudden cry, the crew swings into action, rowing and paddling to the rapid cadence of time-honored chants. On his perch the harpooner is at ease, even when the boat pitches, slews, and yaws in stormy weather. Finally he tenses and, in a great leap, flings himself on the prey and drives in the harpoon. Yes, the harpooner always jumps onto the back of the whale, shark, or ray—such leaping greatly increases his accuracy and killing power. Although pulled

Looking for a quick kill, they dived beneath the massive manta ray and stabbed it.

along by the frantic animal, he swiftly grabs an outrigger and slides smoothly back on board.

I watched once as a wounded manta ray dived rapidly, the wrist-thick palm-fiber rope attached to the harpoon pole flying overboard in spinning coils, lethal to anyone who might get caught in them. At last the rope went slack, and as the men strained to haul up the struggling fish that must literally have weighed a ton, they sang a loud song that they believe is heard by a ray's spirit. "We do not hunt for fun," they sang. "We desperately need your meat to live, to feed our hungry children." Part incantation, part plea, such a song must appease the ray's spirit before the fish can be killed. When the ray was near the surface, several men jumped overboard. Looking for a quick kill—a ray's thrashing wings can span twenty-five feet and break both men and boat—they dived beneath the massive fish and stabbed it with long-bladed, bamboo-handled knives. The fish was cut into chunks at sea; the rest of the butchering would be done on dry land. When a whale or shark is caught, it's lashed alongside the boat and hauled slowly to shore.

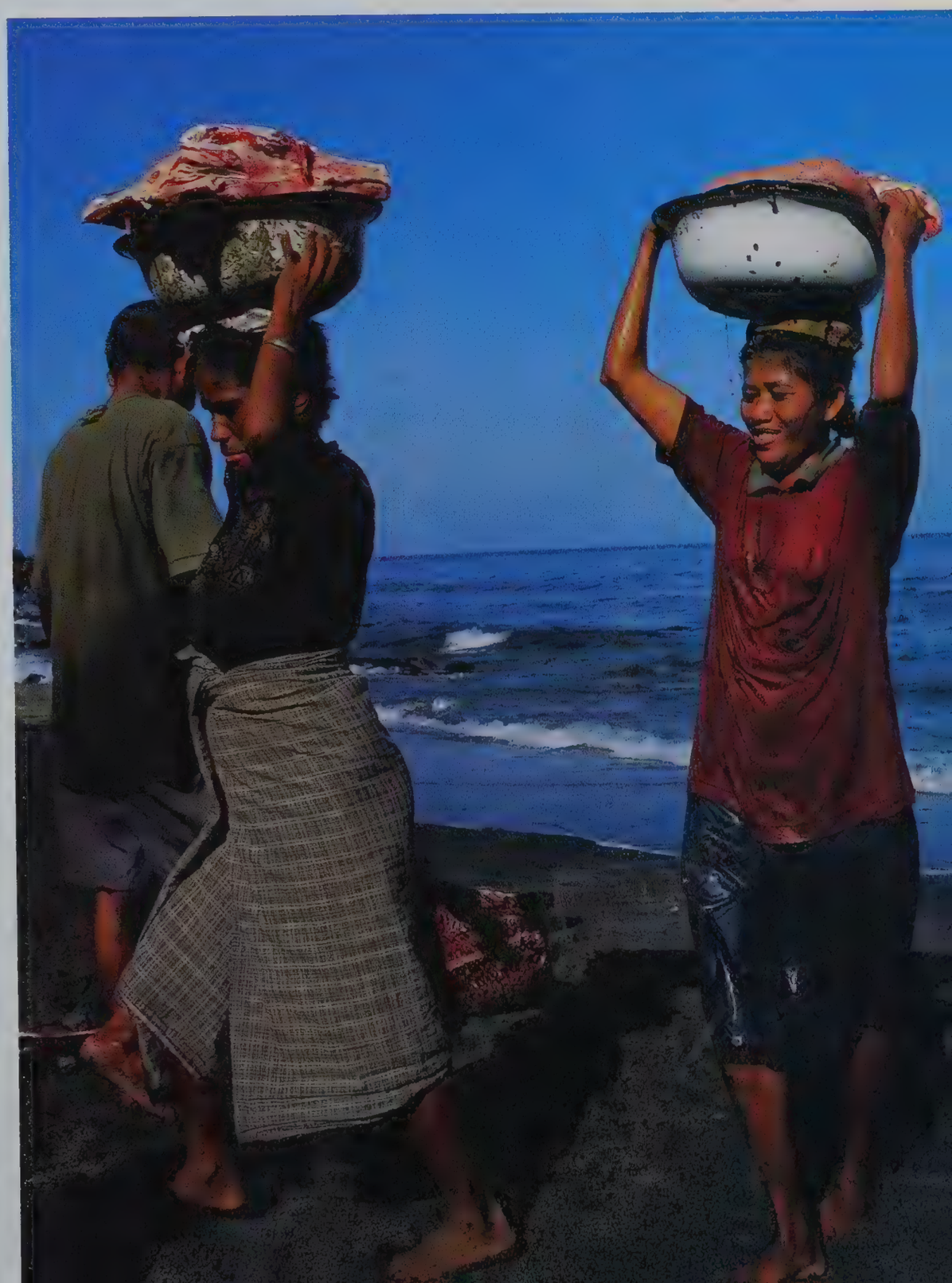
In Lamalera, life is lived on the seashore. Children play in the surf; old men sit in the shade, smoking thin cigarettes rolled with strips of lontar palm leaf, talking about long-ago hunts, weaving new sails, or braiding new ropes. But the instant a boat rides in on a soaring swell, all the males, from tots to aged men, rush to help haul the boat up onto the beach. Then the kill is cut up and divided among members of the boat clan, as well as the sail-

makers and boatbuilders. Shares are determined by custom, with the biggest portion going to the harpooner. His share is called *leí nakē*, "the wages of his feet," in tribute to his balance on the narrow platform; he in turn is obliged to present his share to the oldest male in his direct paternal line.

The meat and fat are sun-dried on racks, and every part of the animal is used. It is considered sinful—and an offense to the dead animal's spirit—to waste anything. About half the bounty is kept in the village. The rest is traded: Lamalera, an almost moneyless society, depends primarily on barter.

Every Saturday at dawn, the women and girls walk five miles to a market at Wulan Doni, where they trade with women from many mountain villages. Carrying heavy basins of meat and fat on their heads, they proceed straight-backed along a path used by untold generations. At the market, women from the mountain villages spread agricultural produce under the trees. The women of Lamalera sit apart. Once they and the others have paid a tiny tribute to a few families that keep the market area clean, a whistle shrills and the bartering begins. There is little or no haggling, because every item has a traditional value: a piece of dried whale meat two fingers wide and a hand-length long, for example, is worth twelve bananas. In the afternoon, the Lamalerans set off for home with basins of maize, rice, yams, bananas, cassava, and other fruits and vegetables.

In 1973, in an effort to modernize the sea hunt, the UN's Food and Agriculture Organization (FAO) sent a whaling ship, along with a Norwegian master whaler, to Lamalera. The experiment lasted three years, and it nearly wrecked the barter-based economy and harmony of the village. The FAO's final report concluded that the hunters "have evolved a method of whaling which suits their natural resources, cultural tenets and style." Many Lamalerans have left in search of a different life, of course. Several are Catholic priests, some ordained in Rome and Berlin; other emigrants include a professor of linguistics, a general in the Indonesian army, the captain of a luxury liner, civil servants, and businessmen working throughout Indonesia. But in Lamalera the boats still sail at dawn, the golden sails unfurl, and sunburned men invoke the blessings of God and the ancient spirits so that their hunt may be successful and they may make it home alive. □



After a whale is butchered at the water's edge, women carry basins of meat and fat to be dried on racks farther up the beach.

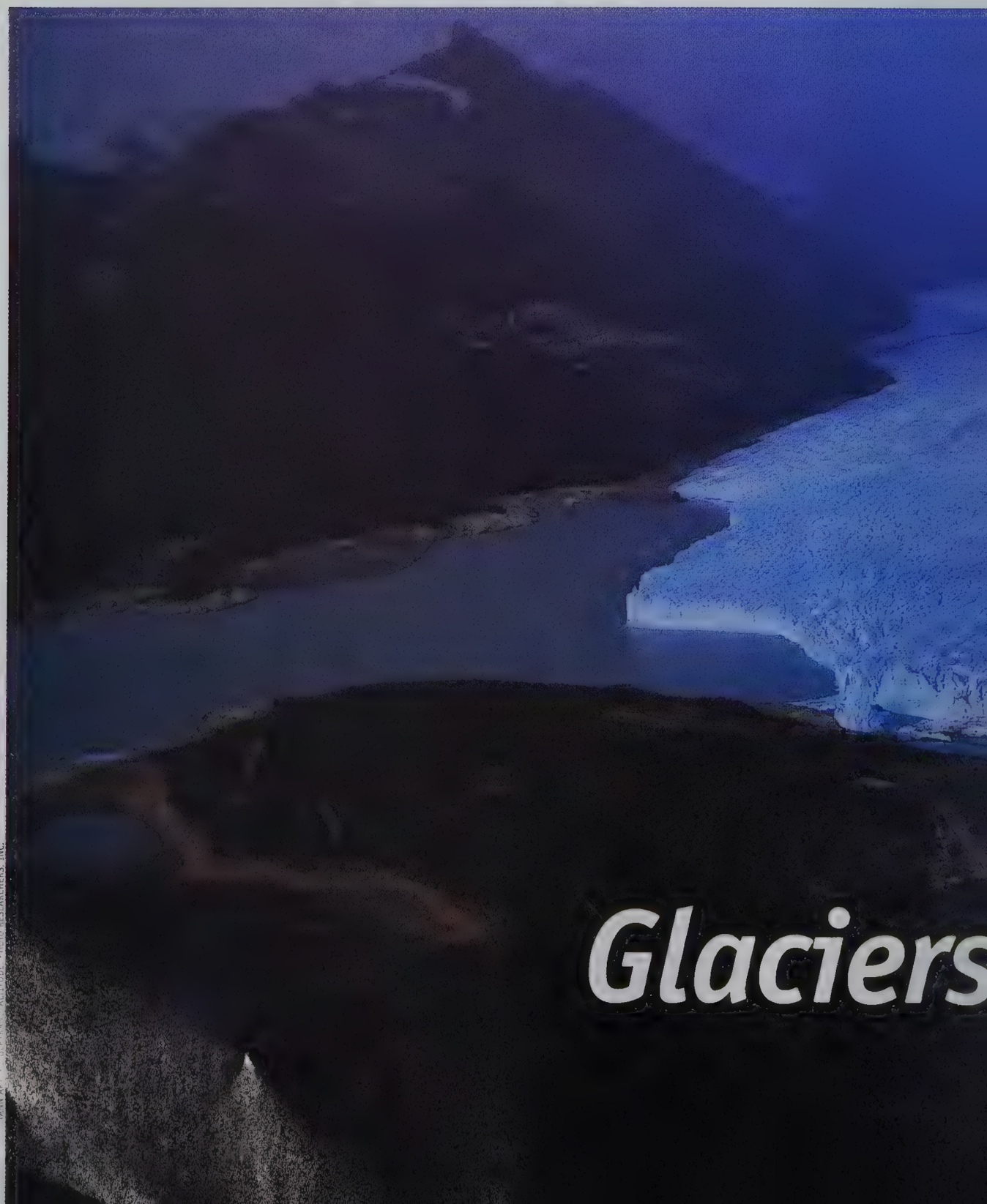
Glaciers

By Wallace S. Broecker

A century and a half ago, the world's mountainous regions were somewhat colder than they are today. We know this because historical records—writings, paintings, early photographs—show that glaciers were larger then. In the Swiss Alps, the area for which the most detailed documentation is available, glaciers expanded during the Little Ice Age, a cold episode that ran from about 1300 to 1860. (This ice age is called "little" because, even at its worst, the cooling required to produce it was only one-tenth the cooling that induced the "big" ice age that peaked 20,000 years ago.)

Though records for glaciers in other parts of the world are less detailed, we know that in the high peaks of the tropical Andes, in the temperate-zone Andes of Chile and Argentina, and in the Southern Alps of New Zealand's South Island, glaciers were substantially larger in 1850 than they are now. So we suspect that the Little Ice Age cooled not just Europe but the world.

The Little Ice Age ended abruptly. Starting in

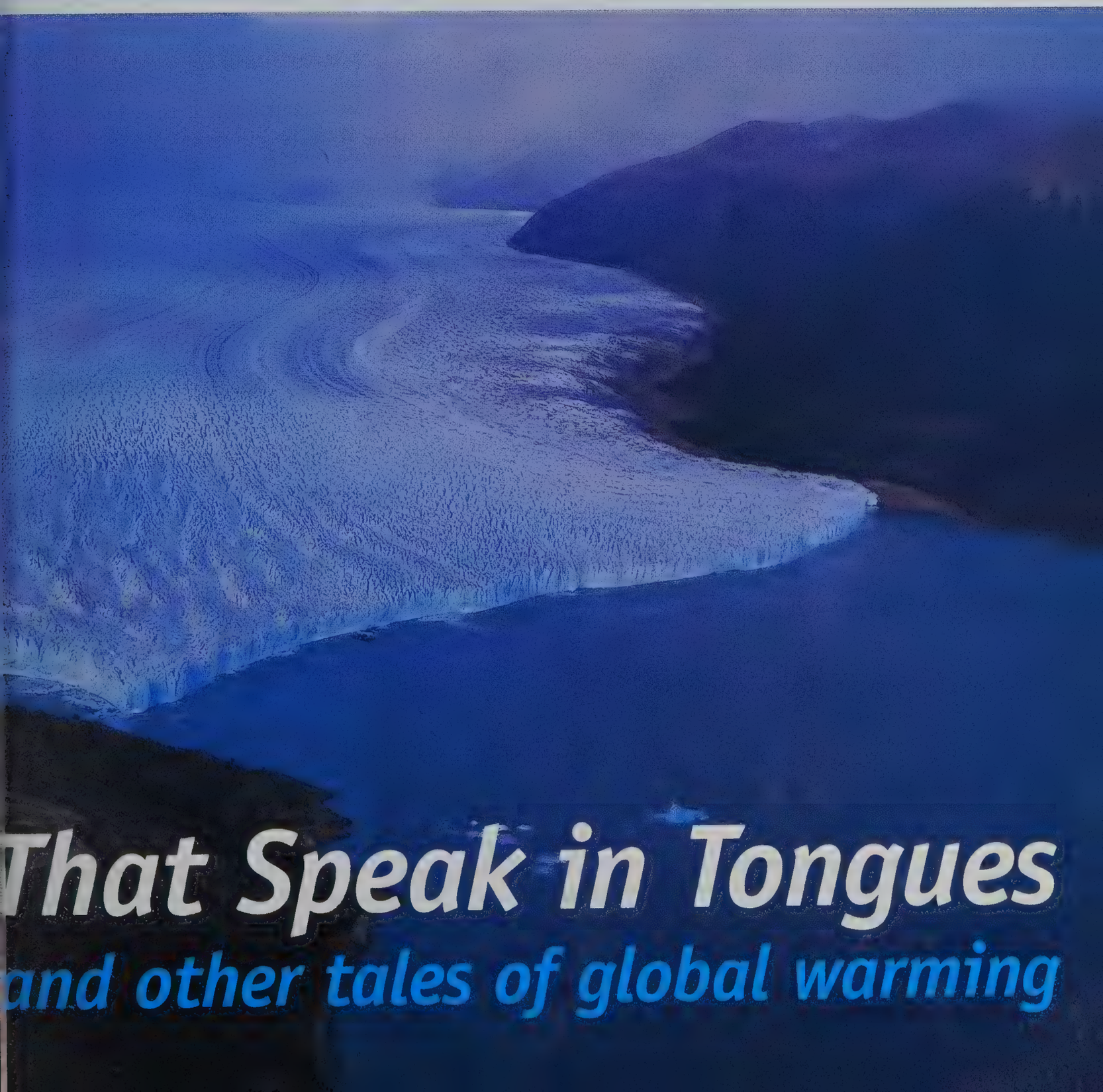


The Perito Moreno Glacier advances into a lake in southern Argentina.

YANN AR[illegible] BRADY/ALTITUDE; PHOTO RESEARCHERS, INC.

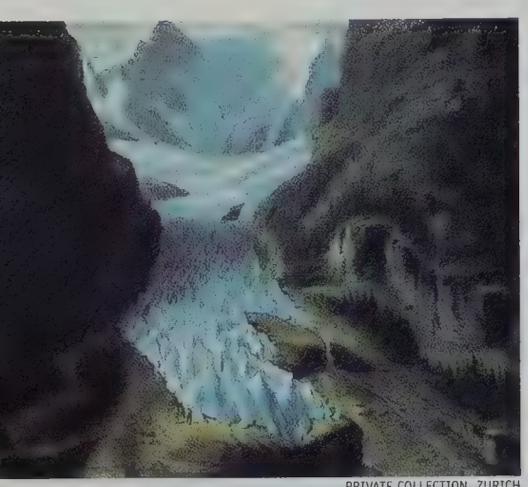
1860, the world's glaciers began a retreat that has continued right up to the present. Without a doubt, therefore, planet Earth has gotten warmer over the past century and a half. But humanity's exact contribution to the warming is still under debate. Along with most atmospheric scientists, I take very seriously the results of computer simulations showing that human-produced forces are very likely driving the rise in temperature that we have seen over the past quarter century. Yet roughly half the overall warming since 1860 occurred before carbon dioxide (CO_2) emissions from human activities had reached significant levels. Some take this as evidence that most of the current upswing in temperature is merely a continuation of the natural events that brought the Little Ice Age to a close.

To truly understand the scenario of global warming, we need to know how much Earth's temperatures would have fluctuated in the absence of the Industrial Revolution and whether we are now exacerbating or counteracting these fluctuations. And we can know these things only if it can



That Speak in Tongues

and other tales of global warming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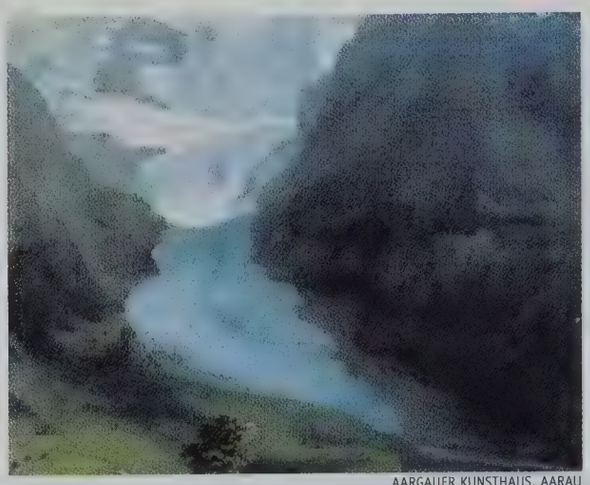
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The lower Grindelwald Glacier in Switzerland once reached down into a populated and accessible valley, making it a popular tourist attraction. The many artists' representations of the glacier enable present-day climatologists to reconstruct its variation over time. Four such depictions, left to right, showing the glacier in 1748–49, 1774–76, 1794, and 1826, are by Emanuel Handemann, Caspar Wolf, Joseph Anton Koch, and Samuel Birmann, respectively.

be shown that Earth has had predictable temperature cycles during the past several thousand years. Many scientists doubt that such large-scale regularities exist, but assuming for the moment that they do, how would we detect them? Even year-to-year changes in average global temperature are difficult to chart, despite the help we get from the worldwide network of thermometers and from the scores of satellites orbiting high above Earth. Getting a sense of relevant natural fluctuations is especially difficult because during the period that geologists call the Holocene Epoch (the 11,000 years since the end of the last ice age), Earth's temperatures have been remarkably stable. Unlike the previous 100,000 years, when the climate underwent numerous large jumps and drifts, measured in many degrees Fahrenheit, the changes during the entire Holocene have been only 1° or 2° F—too small to ascertain with the natural climate indicators we have been using until now (such as tree rings and fossil pollen), whose accuracy is no better than 2° F.

This is why climatologists have turned to mountain glaciers. The record created by these glaciers is an excellent proxy for climate, standing in for hundreds of years of thermometer readings. Not only does this proxy tell us about past temperatures, its margin of error is less than 0.4° F.

Everywhere on Earth, the higher you climb, the colder it gets. The reason is that as air rises, it expands and therefore cools. On average, air temperature changes at a rate of 1° F for every 300 feet of elevation. At some point on the way up, air temperature reaches the freezing point. Glaciers can't form or endure, of course, unless the air temperature remains low, and how far down a mountain they reach depends on what glaciologists call the equilibrium snowline—the boundary between an upper zone where accumulation of snow outpaces melting and a lower zone where the reverse is true. This boundary corresponds fairly closely to the altitude at which air temperature reaches the freezing point. In the Alps, large glaciers have tongues of ice streaming down past the equilibrium snowline and on into valleys in the lower zone. The melting in such tongues below the snowline is balanced by the downward flow of ice from above the snowline. When the air temperature shifts, such tongues can shrink or enlarge dramatically. For example, since 1860 the Rhône Glacier, in the Alps of southwestern Switzerland, has retreated about three miles in response to a rise in the equilibrium snowline of about 300 feet. This rise corresponds to an atmospheric warming of slightly more than 1° F.

Records of glacial advances and retreats provide an accurate gauge of temperature changes.

Such astounding sensitivity suggests that a record of glacial advances and retreats during the Holocene Epoch would yield the information we seek about recent climate cycles. But this is easier said than done. The problem is that glaciers act like giant erasers. Each advance eradicates almost all traces of what's come before. At their greatest size during the Little Ice Age, Europe's glaciers covered an area at least as large as was covered in any previous Holocene advance, so the record of earlier Holocene advances is mostly obscured.

We do, however, have evidence that well before the Little Ice Age—several times during the past 11,000 years, in fact—Alpine glaciers pushed out to roughly the same position they occupied in 1850. One such indication is the size of the moraines—the looping walls of debris that mark the edge of each major Alpine ice tongue. These piles of rocky rubble are huge, some standing 300 feet above the valley

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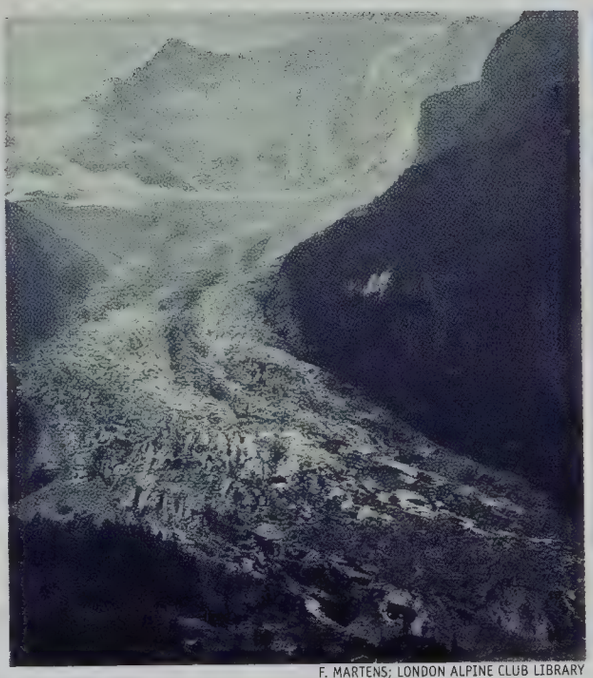
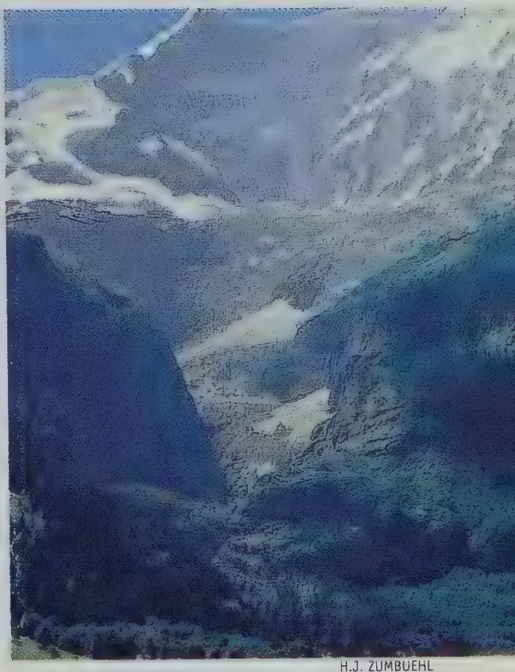


F. MARTENS; LONDON ALPINE CLUB LIBRARY



H.J. ZUMBUEHL

Photographs of the lower Grindelwald Glacier taken in 1858 and 1974 demonstrate how much it has shrunk since the end of the Little Ice Age, a relatively cool period that lasted from about 1300 to 1860.

floor. It is difficult to imagine that they could have been formed during a single forward push of ice; instead they appear to be the result of a great many such pushes in the course of thousands of years. Within these huge debris piles are layers representing ancient soils, indicating that many earlier advances occurred. But carbon 14 dates derived from soil materials are often misleading and so cannot be relied on to provide the precise chronology we seek.

During the last decade, however, a major breakthrough occurred, owing to the appearance of a new climate proxy: wood and peat that have been washing out from beneath the retreating Alpine glaciers. For this kind of material, carbon dating is quite reliable and allows us to determine precisely the warm periods when trees and other plants were able to grow in places that are now covered by glaciers.

In September 2000, I had the opportunity to witness a harvest of this ancient wood and peat when Christian Schluechter, a University of Bern geologist who pioneered such studies, led a small group of interested scientists to the terminus of the Unteraare Glacier in the northern Swiss Alps. He explained to us that once each year, toward the end of summer, the meltwater that has accumulated beneath the ice suddenly breaks out of its confinement and sweeps over an apron of large cobbles lying at the foot of the glacier. To our amazement, we saw pieces of wood and peat wedged here and there among the cobbles. During the single hour our helicopter taxi service allotted us for exploring the apron, our group found fifty separate pieces. Many of them showed evidence of compression, shearing, and twisting caused by the weight and motion of the overlying ice.

Our finds were not the first "warm artifacts" to be harvested from the forelands of retreating Swiss glaciers. Schluechter and his colleagues had been collecting wood and peat fragments for several years and have obtained carbon dates for nearly a hundred of them. Some of the wood dates all the way back to the earliest Holocene. Even more important, rather than being spread evenly through time, the dates for these pieces of wood and peat fall into distinct groups, with each group presumably representing a warm episode when Alpine glaciers were even smaller than they are today.

Geologists are now investigating whether these groupings correspond to another new source of evidence of cyclic patterns in Earth's recent history. This evidence comes from studies of sediment in the deep waters of the North Atlantic. The rock fragments in these sediments are much too large to have been transported there by ocean currents; they could have reached their present location only by having been frozen into large icebergs that floated long distances from their point of origin before melting. During the past decade, Gerard Bond, my colleague at Columbia University's Lamont-Doherty Earth Observatory, has studied the makeup of such ice-rafted debris. Noticing that some of the sediment grains were stained with iron oxide, he reasoned that they must have come from locales where glaciers had overrun outcrops of red sandstone. Bond concluded that a detailed analysis of deep sediment cores would reveal changes in the mix of sediment sources over time. This proved to be an excellent strategy, for Bond found something so unexpected that it stunned all of us who study climate history. The proportion of these red-stained grains fluctuated back and forth over time from lows of 5 percent to highs of about 17 percent, and

ILLUSTRATIONS FROM PLATE 3.8, COPYRIGHT © 1999 BY HEINZ J. ZUMBUEHL, INSTITUTE OF GEOGRAPHY, UNIVERSITY OF BERNE, FROM "HOLOCENE GLACIAL FLUCTUATIONS," BY H. HOLZHAUSER AND H.J. ZUMBUEHL, IN *HYDROLOGICAL ATLAS OF SWITZERLAND* (BERNE: FEDERAL OFFICE OF TOPOGRAPHY/FEDERAL OFFICE FOR WATER AND GEOLOGY, 1999)

these fluctuations had a pattern: a nearly regular, 1,500-year cycle. Even more amazing, he found that the cycles ran virtually unchanged, in both amplitude and duration, through both ice-age and non-ice-age periods during the last 100,000 years.

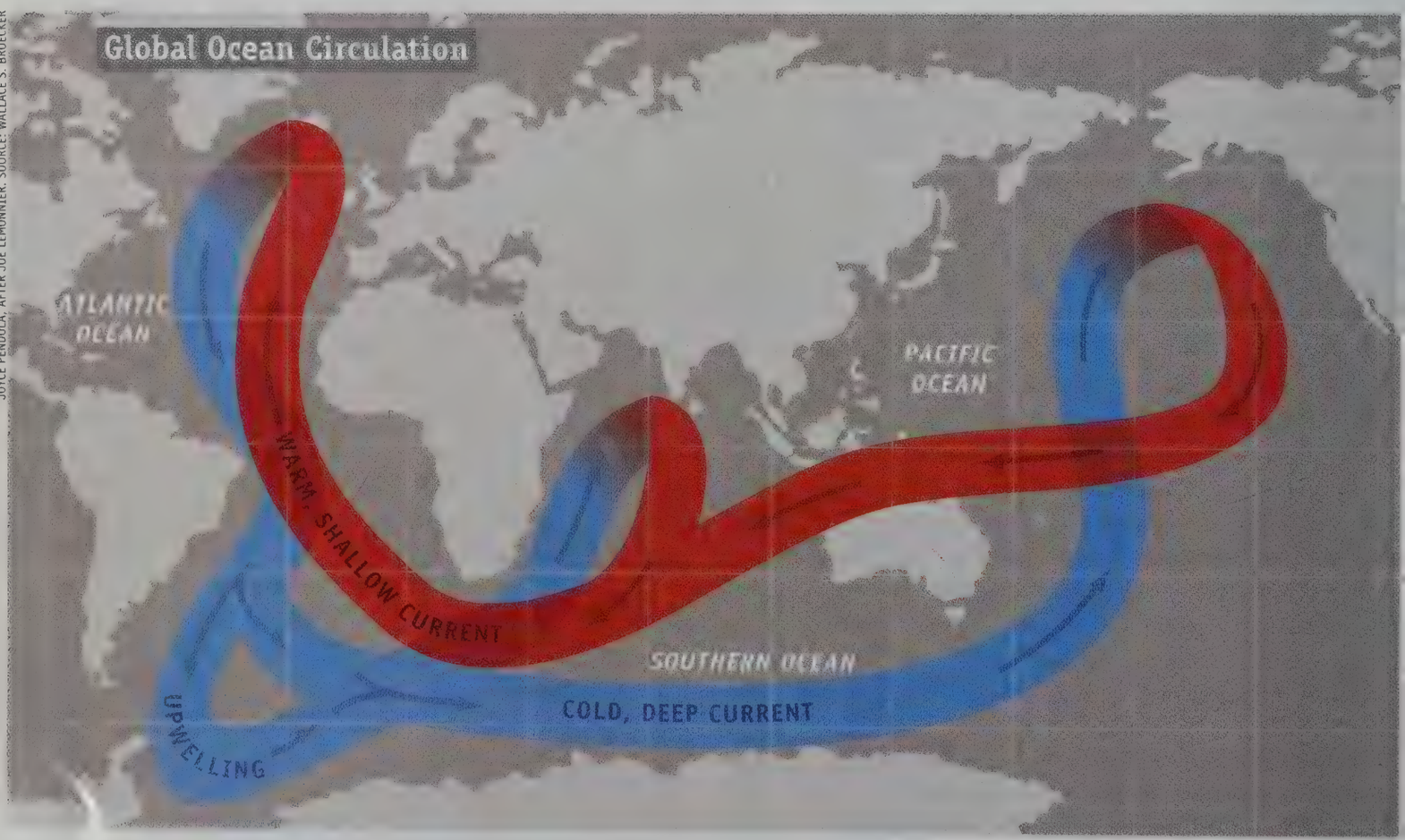
Bond puzzled over what might be pacing this cycle. As a geologist, he knew that the sources of the red-stained grains were generally closer to the North Pole than were the places yielding a high proportion of "clean" grains. At certain times, apparently, more icebergs from the far north were making their way well to the south before finally melting and shedding their sediment. Bond hypothesized that the alternating cycles might be evidence of changes in ocean-water circulation.

Ocean waters are constantly on the move, and water temperature is both a cause and an effect. As water cools, it gets denser and sinks to the bottom. In one part of what I like to call the "bipolar seesaw," the bottom layer of the world's oceans comes from cold, dense water sinking in the far North Atlantic (see diagram, below). This causes the warm surface waters of the Gulf Stream to be pulled northward, as they are today. Bond realized that during this part of the ocean cycle, a large proportion of the icebergs that bear red grains would melt while still fairly far north. But sometimes the ocean reorganizes itself, and the Southern Hemisphere holds sway in driving ocean circulation. At such times, surface waters in the North Atlantic would generally be colder, permitting icebergs bearing red-stained grains to travel farther south before melting and depositing their sediment.

The onset of the Little Ice Age in about 1300, which followed the so-called Medieval Warm Period of the eighth through tenth centuries, may represent the most recent time that such a switchover occurred. The contrast in the North Atlantic is apparent if we consider that in the tenth century, Erik the Red and his band of Vikings colonized the lands surrounding the fjords in southwestern Greenland. Not only did the Vikings navigate their wooden vessels back and forth between Scandinavia and Greenland without being thwarted by sea ice, but they were also able to grow enough grass to support sizable flocks of sheep. As time went on, however, conditions deteriorated. The last recorded communication from the colonists occurred in the early fourteenth century—just at the onset of the Little Ice Age in the Alps—and eventually the colony died out (see "The Vikings' Silent Saga," *Natural History,* November 2000).

Further evidence of the impact of the Little Ice Age comes from records kept by Icelanders, whose

The present-day pattern of ocean circulation appears to be driven by the sinking of dense, cold water in the North Atlantic. This draws a flow of warm surface water (the Gulf Stream) far to the north. Disruption of this pattern in the past led to the cooling of lands bordering the North Atlantic, such as Greenland, Iceland, and northern Europe.



JOYCE PENDOLA, AFTER JOE LEMONNIER. SOURCE: WALLACE S. BROECKER

writings indicate that between 1650 and 1850, their island was icebound for several months each year—a great hardship, since fishing was a main source of sustenance. They reported with pleasure that the ice began to wane in 1880, permitting them to extend the fishing season. Readings from their thermometers (which they began to use in about 1870) also suggest that the mean annual temperature was rising.

Could it be that these ocean oscillations, because of their effect on air temperature, also explain the snowline fluctuations seen in the Swiss Alps? So far, none of the wood or peat fragments sluiced from beneath the ice have yielded carbon 14 dates from the eighth through the thirteenth centuries, which would correspond to the Medieval Warm Period and the interval leading up to the Little Ice Age. But another source of evidence demonstrates that Alpine glaciers were smaller during this time. Medieval farmers living below the huge Aletsch Glacier, in what is now south-central Switzerland, constructed a crude aqueduct of hollowed-out

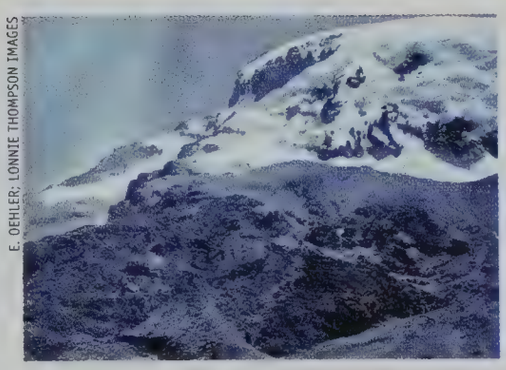
A 1,500-year cycle in ocean temperature affects how far south North Atlantic icebergs can travel.

larch tree trunks to carry water from a small mountain lake down to a village. We know from written records that parts of this aqueduct had to be rebuilt after being overrun by the 1350 advance of the Aletsch Glacier.

If future dating of wood and peat expelled from beneath retreating glaciers in the Alps and other mountainous regions worldwide supports Bond's 1,500-year cycles, and if the Medieval Warm Period/Little Ice Age oscillation can be shown to be part of the most recent of these cycles, we will have taken an important step toward establishing a major natural rhythm in Holocene Epoch temperatures. This rhythm could then be extrapolated into the future. Because the midpoint of the Medieval Warm Period was about A.D. 850, an extension of Bond's cycles would place the midpoint of the next warm interval in the twenty-fourth century.

While offering a useful basic framework, this pattern alone does not account for all aspects of past fluctuations and thus is not a sufficient predictor for the future. For example, we usually think of cycles as having a regular, bell-like shape. But during the millennia corresponding to the last ice age, Bond's 1,500-year cycles were closer to rectilinear, indicating sudden starts and stops. As is clearly recorded within the deep layers of Greenland's ice, the transitions often took just a few decades. This abruptness was especially pronounced as the climate warmed. Has this also been the case during our own epoch, the Holocene? If the Holocene's "Bondian" cycles, too, have been rectilinear, one would expect the post–Little Ice Age warming to have been completed within a few decades. One would also expect that in the absence of the Industrial Revolution, global temperature would have stabilized for a warm plateau of several hundred years. But in fact, global temperatures in the decades immediately after the Little Ice Age did not simply jump to a new plateau.

Also, studies of Alpine glaciers show that the Little Ice Age had three cold peaks, in about 1350, 1650, and 1850. Do we have any clues about the causes of these additional, smaller fluctuations? I pondered this problem in the early 1970s. At the time, Holocene climate records were few and far between. In fact, only one—a 70,000-year record obtained from a one-mile-long, four-inch-diameter ice core drilled in northern Greenland—had enough length and detail to provide any clues. Danish paleoclimatologist Willy Dansgaard and his colleagues had managed to obtain paleotemperature results from samples of this core and had concluded that much of the variation in climate could be accounted for by a combination of 80-year and 180-year cycles, which they thought reflected periodic fluctuations in the Sun's energy output. When I merged Dansgaard's pattern with that of the warm-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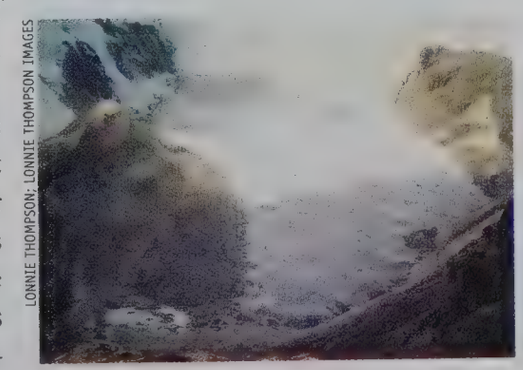
Tanzania's Kilimanjaro has lost more than four-fifths of its summit ice in the past century. Above left, the peak in 1912; at right, in 2000.

Qori Kalis Glacier in the Andes of southern Peru: Photographs taken in 1978, below left, and 2000 provide more evidence that global warming is a worldwide phenomenon.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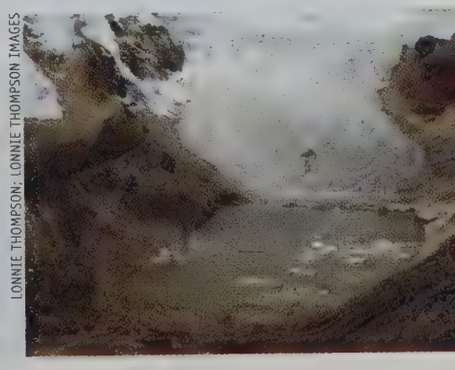
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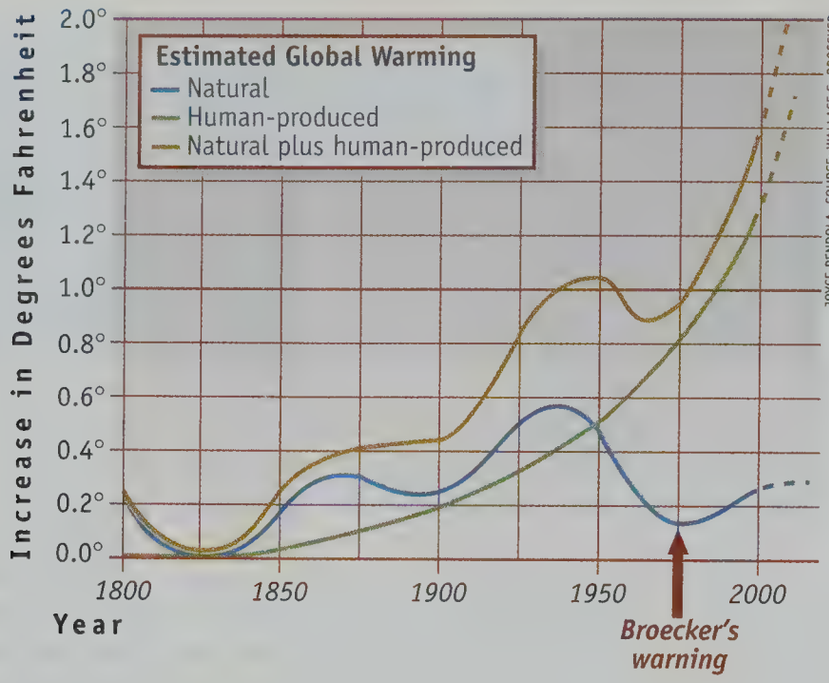


JOYCE PENDOLA. SOURCE: WALLACE S. BROECKER

ing expected from the steady increase in man-made greenhouse gases, I obtained a composite that matched the major features of the actual global thermometric record—namely, a warming phase extending from 1860 to the time of World War II and followed by a thirty-year pause (see graph, above). I predicted that when, in the near future, Dansgaard's natural cycle turned from a cooling into a warming phase, the natural and the man-made factors would join forces and produce a prominent renewal of the warming trend. My warning was published in the journal *Science* in 1975. In 1976 the thirty-year plateau came to an end, and the warming that then began has continued right up to the present.

My prediction was correct, but was it soundly based? Ten new ice-core records—from Greenland, from Antarctica, and from high-mountain sites elsewhere on the planet—are now available. None show Dansgaard's combined 80-year and 180-year cycles. I thus have been inclined to write off the success of my prediction as just a happy accident. Still, the changes we are attempting to document have a magnitude of only a few tenths of a degree,

CHRISTIAN SCHLUECHTER

Above: Though the cumulative global warming since 1800 amounts to less than 2° F, it is expected to increase, owing mainly to the contribution of human-produced climate effects. In 1975 the author warned that an upturn in the natural cycle would reinforce these human-produced effects. Right: Wood washed from beneath Switzerland's Unteraare Glacier.

and perhaps in most records they are masked by regional climate change.

What drives Bond's 1,500-year cycle? High on the list of possibilities must be the Sun. But sufficiently accurate, satellite-based measurements of solar activity cover only the past twenty years—not long enough to warrant our drawing firm conclusions. We do, however, have a longer-term record of the number of dark spots resulting from magnetic storms on the Sun's surface. These spots usually wax and wane in an eleven-year cycle. During an interval known as the Maunder Minimum (A.D. 1650–1710), however, no sunspots were observed. Minze Stuiver, an isotope geologist at the University of Washington, has shown that more carbon 14 atoms were created in our atmosphere during the Maunder Minimum than either before or after it. The reason, Stuiver postulated, is that the electrically charged particles streaming out of sunspots generate a magnetic field that deflects incoming cosmic rays from our solar system. During periods of low sunspot activity, such as the Maunder Minimum, however, the magnetic shield is turned off and more cosmic rays bombard Earth's atmosphere, manufacturing extra carbon 14 atoms. Having demonstrated the link between sunspots and carbon 14 production, Stuiver was then able to use carbon 14 measurements on tree-ring-dated wood to deduce sunspot minimums prior to the invention of the telescope. His data indicate that these occurred at roughly two-century intervals and might be the cause of Dansgaard's 180-year cycle. Stuiver's record contains no hint of Dansgaard's 80-year cycle or of Bond's 1,500-year cycle, however.

If not the Sun, then what might be the driver of Bond's cycle? For me, the top candidate remains the ocean's bipolar seesaw. In the global ocean circulation pattern we are accustomed to seeing, sinking cold surface water in the North Atlantic is replaced by warm Gulf Stream waters, which are drawn northward. What may underlie this pattern is actually salt, since an extra gram of salt per liter makes seawater denser by an amount equivalent to a cooling of 8° F. The North Atlantic is unusually salty, because the location of mountains and the direction of prevailing winds lead to the export of water vapor from the Atlantic to the Pacific Ocean. The salt left behind makes that surface water not only saltier but denser, and the water sinks in the familiar pattern.

Meanwhile, acting like a giant conveyor belt, the normal circulation of the world's oceans transports excess salt out of the Atlantic Ocean. This

process may not occur at a steady rate. Rather, it may oscillate, leading to Bond's 1,500-year cycle. As I see it, at times the conveyor mechanism carries salt away faster than it is being replaced. This may lower the water density in the North Atlantic enough to make the conveyor shut down. At this point, the warm Gulf Stream weakens, and the circulation pattern reorganizes itself under the domination of the Southern (Antarctic) Ocean. With the new regime, salt ceases its rapid departure from the North Atlantic, and salt levels there begin to rise again. When the northern waters are again dense enough to rejuvenate deep-water formation in the North Atlantic, the cycle is complete.

The details of this mechanism are still not clear, but what *is* clear is why such a cycle might lead to warmings and coolings of the lands surrounding the North Atlantic. When the north rules, an enormous amount of heat—as much as would be generated by a million large power plants—is carried north of the Strait of Gibraltar by the Gulf Stream. This heat is released into the atmosphere in winter and is carried to northern Europe by the prevailing westerly winds. When the south rules instead, this source of heat is lost and the Alps cool.

Are underlying natural cycles retarding or reinforcing human-induced global warming?

But how does any of this explain the cooling in the Southern Hemisphere—the Little Ice Age in New Zealand's Southern Alps and in South America's Andes? Instead of being limited to the land area adjacent to the North Atlantic, this cold episode appears to have affected much of the planet. There must have been some link between patterns of ocean circulation and conditions in the atmosphere that affected both hemispheres. Although the nature of this link has not been discovered, it probably involves Earth's "tropical heat engine"—the way air rising from the equator fuels the atmosphere with heat and water vapor.

So where do we stand? For a start, certain regular fluctuations in the Holocene climate seem to occur, but scientists are still left with many uncertainties about them. This prevents us from making a meaningful prediction concerning how the climate would have changed in the absence of the Industrial Revolution. We cannot prove the existence of either the 1,500-year cycle—which the available Greenland ice cores fail to record—or the combined 80- and 180-year cycles. However, we can state with some confidence that natural Holocene temperature fluctuations have been on the same scale as the human-caused effects estimated to result from greenhouse gases. Hence, we cannot assume that in the absence of human intervention, Earth's temperatures would have remained stable.

Unfortunately, we cannot even say whether natural changes are at this point retarding or reinforcing human-induced greenhouse warming. The situation will be much clearer two decades from now,

GEORGE H. DENTON, UNIVERSITY OF MAINE

Rock debris surrounds a lake below Hooker Glacier, in New Zealand's Southern Alps. The debris is a residue of the glacier's advances during the Little Ice Age.

however, as computer simulations predict an additional 1.5° F warming by the year 2020. If such an increase in global temperatures occurs, there will not be any doubt: natural causes alone would not have been sufficient to account for it.

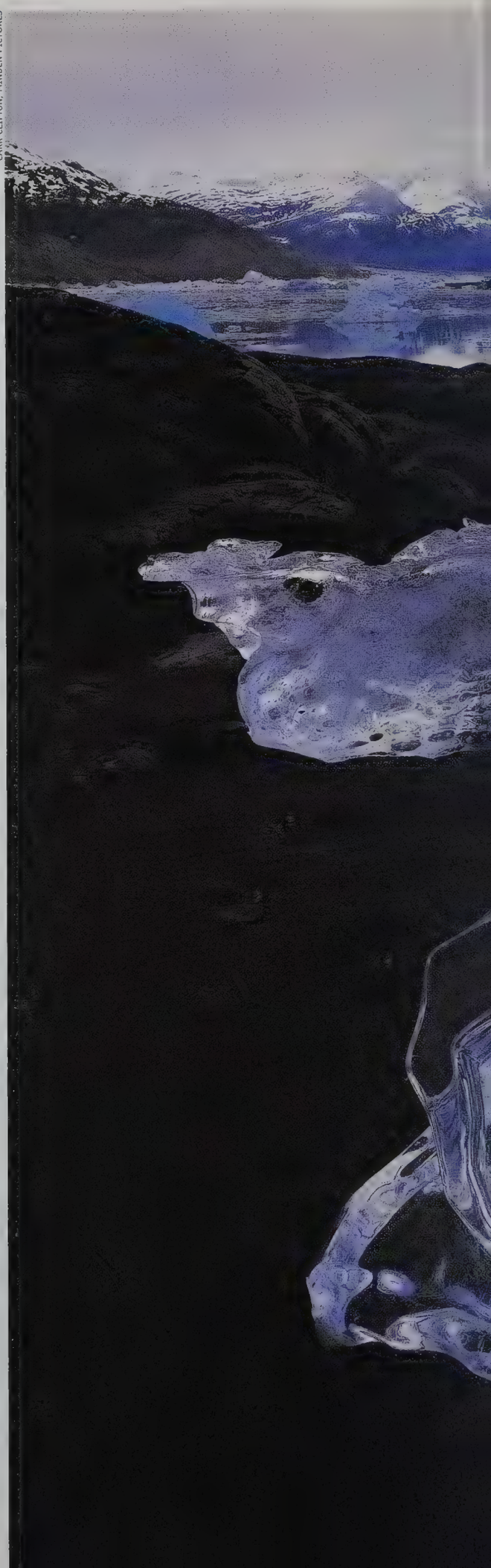
Does this mean we can all sit back, do nothing, and wait for the results to roll in? Certainly not. In twenty years, we may well conclude that we must stem the rise of CO_2, and if so, we've got a lot of preparation to do. Very likely, fossil fuels will remain our primary source of energy. With more people and a higher standard of living in the less developed countries—and with even a sustained per capita level of demand in the United States—energy use will at least double by the year 2050. We must learn how to remove CO_2 from power-plant exhausts and

We may have to remove CO_2 from power-plant exhausts and even from the atmosphere itself.

probably from the atmosphere itself. (Estimates of the cost of CO_2 removal suggest that it would add a few cents per kilowatt-hour to the cost of electricity or about forty cents per gallon to the cost of gasoline.) Plus, of course, the CO_2 we remove must be put somewhere: stored in the deep ocean or in deep saline aquifers or, if we want to be sure it never comes back to haunt us, converted into magnesite ($MgCO_3$), a geologically inert mineral. More difficult than the technical aspects are the political ones. Ready or not, we will have to face them all.

To strengthen their case, corporate spokespersons, avid consumers, and plenty of other people and institutions inclined to dismiss the ongoing rise in atmospheric CO_2 as inconsequential may be happy to latch on to the paleoclimatic reconstruction presented here. This would be unfortunate. Unless all the work done on climate simulations and fossil-fuel-use projections is seriously flawed, one thing is certain: our planet will indeed experience a major human-induced warming during this century.

We have learned that Holocene temperatures have undergone natural fluctuations, but the causes of these changes are so subtle that we have yet to figure them out. Apparently, our climate system responds to even tiny nudges. This being the case, the potential effects of human activities should not be underestimated. If we continue along a business-as-usual energy course, we'll be giving the climate a large shove. □



CARR CLIFTON; MINDEN PICTURES

Fragments from Alaska's Columbia Glacier, a thirty-five-mile-long stream of ice that sheds icebergs into Prince William Sound

A small European legless lizard called the slow worm, above, rests on a rock beside its rusty tin shelter.

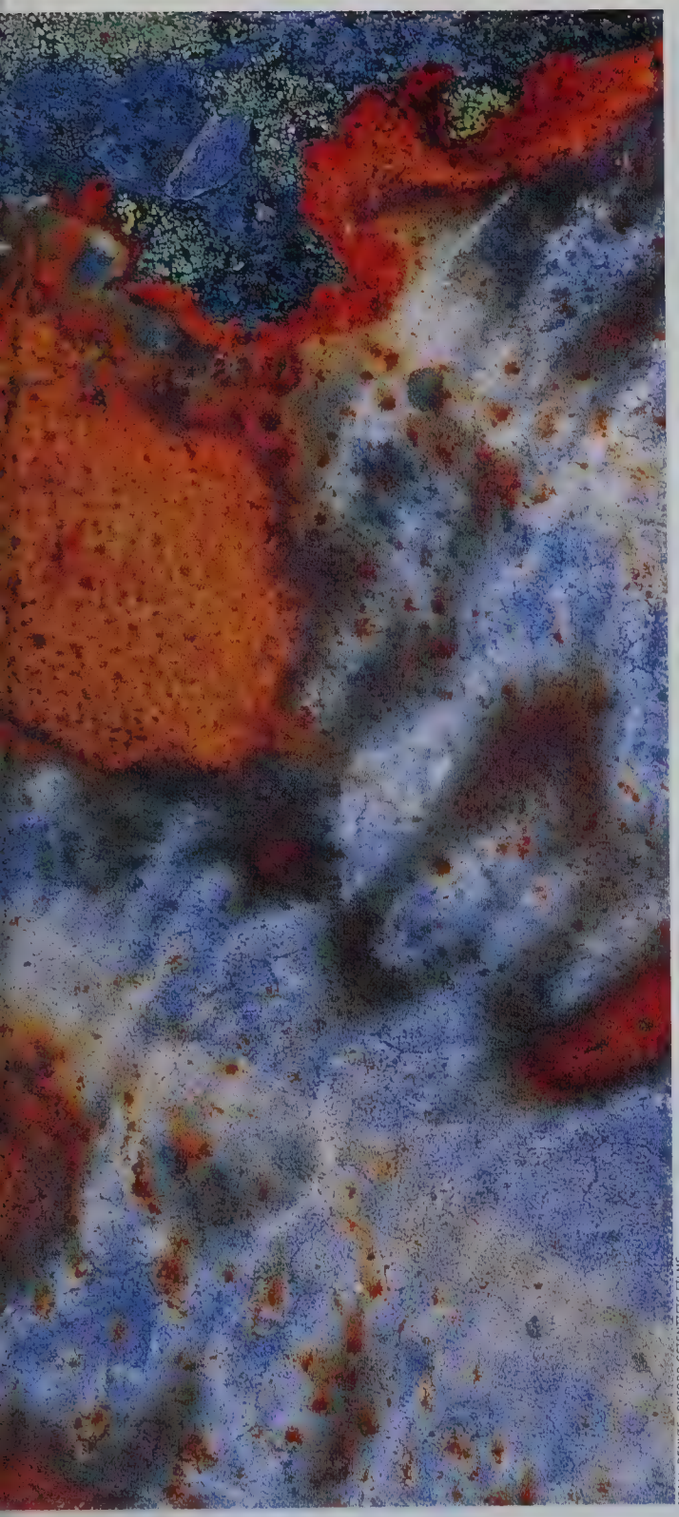
Lizards have legs; snakes don't. This generalization, which many of us learned in grade school, may be useful as a rule of thumb but is surprisingly inaccurate. Some snakes, such as pythons, retain tiny leg bones, which may be visible as minuscule claws at the base of the tail. Perhaps more surprisingly, dozens of lizard lineages have lost their limbs over evolutionary time and are now, at least superficially, indistinguishable from snakes. (Snakes are actually just a highly modified group of lizards, but one characteristic that sets snakes apart is a flexible skull, allowing them to swallow prey larger than their heads.) Limbed and limbless species of lizards may even be found within the same genus. Because these dramatic changes have occurred repeatedly, they provide a wonderful natural experiment that can help us understand how major transformations in body form happen.

With collaborators Jamie Slingluff and Tod Reeder, I have begun to study these transformations from lizardlike to snakelike form. By combining detailed body and limb measurements, evolutionary trees derived from DNA data, and statistical analyses, we have found that this transition involves three

Shape Shifters

Time after time, lizards have dropped their legs in favor of a snakelike body form.

By John J. Wiens



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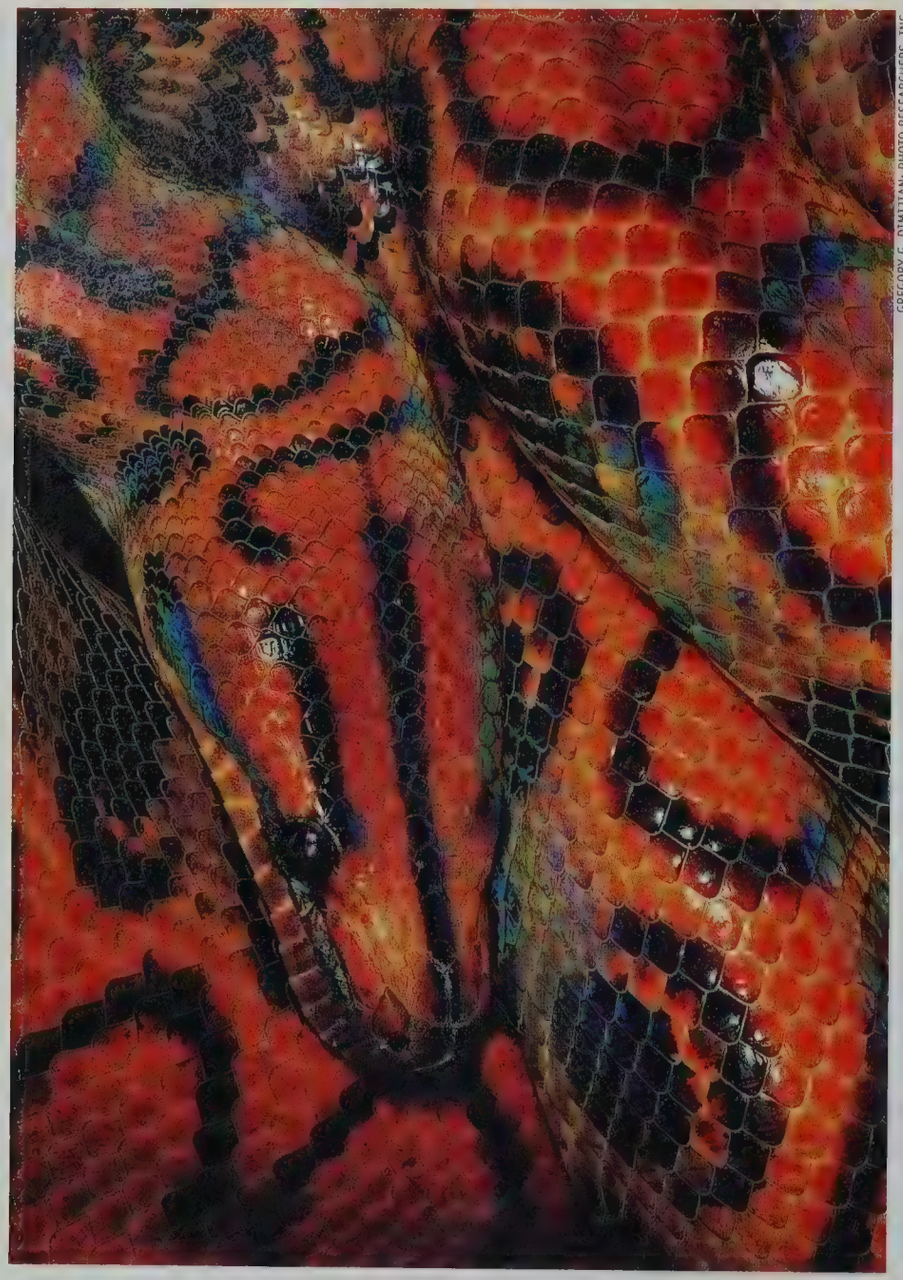
Top: The Eastern racer, a typical snake, is strikingly similar in appearance to a legless pygopodid lizard from Australia, bottom.

tightly correlated evolutionary changes: increase in total length, reduction in limb size, and loss of fingers and toes.

We have also found that despite the overall similarity of snakelike lizards, two distinct types—burrowers and "grass swimmers"—have evolved over and over again. Burrowers tend to be small and to have relatively short tails and long trunks. (The trunk is the body length minus head and tail.) By contrast, grass swimmers live above ground, often in dense grass, and have longer tails and shorter trunks than burrowers do. They may



GREGORY G. DIMIJIAN; PHOTO RESEARCHERS, INC.

While most snakes (such as the rainbow boa, above) have short tails and live above ground, snakelike lizards are generally either long-tailed surface dwellers or short-tailed burrowers. Because the most primitive lineages of snakes are burrowers, short tails in surface-dwelling snakes may be an evolutionary leftover from an underground ancestry.

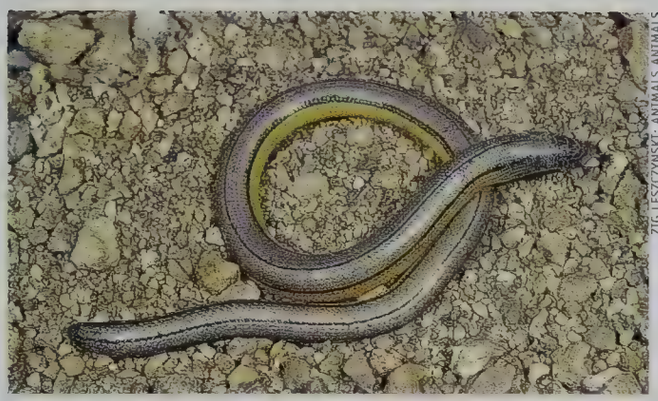
Long-tailed surface dwellers, glass lizards have fragile tails that can break off if grabbed by a predator. A broken tail grows back, though typically in a different color and shorter than the original.

also be considerably larger: some are big enough to eat mice.

The reasons for this dichotomy in body form and habitat are not yet clear, but we have some ideas. Surface-dwelling lizards are exposed to many predators, such as hawks and skunks. The tail, which lacks vital organs for most of its length, is less critical to survival than are other parts of the body, and many long-tailed surface-dwelling lizards, whether limbed or limbless, have tails that break easily when grabbed by an attacker. (Fortunately for the lizards, their tails regenerate.) Indeed, the unusual fragility of the elongate tail in the snakelike genus *Ophisaurus* is reflected in its common name: glass lizard. Burrowers, which spend most of their time hidden from predators, have short tails that are rarely modified for breaking.

The small body size of many burrowers may also help explain their short tails. Trunk space is at a premium in small lizards, because having a tiny

JAMES H. ROBINSON; ANIMALS ANIMALS



ZIG LESZCZYNSKI; ANIMALS ANIMALS

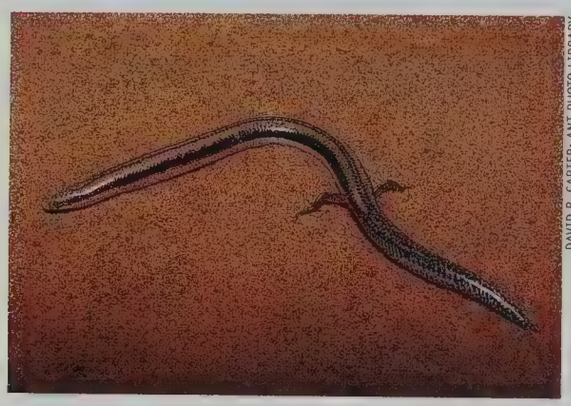
California legless lizards—short-tailed burrowers—are found on beaches and in other sandy habitats.

JACK DERMID; BRUCE COLEMAN, INC.

body cavity can reduce the size and/or the number of young (a potential evolutionary handicap). Increasing the length of the trunk at the expense of the tail may allow small burrowers to maintain enough room for developing eggs or embryos (most of these lizards lay eggs, but some give birth to live young).

The glass lizard above is a grass swimmer whose tail makes up more than two-thirds of its total length. In burrowers (such as the California legless lizard, top right), the tail may be only one-third of the total length.

ROBERT W.G. JENKINS; ANT PHOTO LIBRARY



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ROBERT VALENTIC; NATURE FOCUS

Some groups of lizards have members representing nearly every stage in the transition from lizardlike to snakelike body form. In the Australian skink genus *Lerista*, for example, are species with four limbs, top, two limbs, middle, and no limbs, bottom.

In most lizard lineages that have become snakelike, the front limbs were lost first. The Mexican worm lizard, an exception to this trend, has reduced its rear limbs but has retained well-developed front legs, which it uses for burrowing.

The galliwasp, in the family Anguidae, represents the ancestral four-legged form from which both snakelike, burrowing anguids (e.g., the California legless lizard) and grass swimmers (e.g., the glass lizard) evolved.

We will continue to explore this puzzling dichotomy among snakelike lizards, as well as the more fundamental question of why lizards have repeatedly evolved to become snakelike in the first place. One hypothesis is that reduced limbs and elongate bodies may streamline lizards, helping them move more easily in underground tunnels and through dense grass. To test this hypothesis, our plans include the staging of a "Lizard Olympics"—taking individuals from species representing various points in the transition from lizardlike to snakelike body form and comparing their athletic abilities as they move in different habitats. □

Why so many lizards (including the hooded scaly foot, opposite) evolved a snakelike form is a question that remains unanswered. One hypothesis is that since legs hinder movement in dense grass and in tunnels—two common habitats of snakelike lizards—natural selection may favor their loss.

REVIEW

Volcanoes and marine iguanas of the Galápagos inspired Charles Darwin to imagine a younger world.

Sing the Song of Evolution

Finally, television takes a comprehensive look at Darwin and his ideas.

Frans B. M. de Waal

Before Marxism lost its footing, its pamphlets discussed "post-capitalist" society as if the demise of free enterprise were just around the corner. I am always wary of in-your-face declarations of victory—titles like "The Triumph of X or Y," for instance—since they tend to be either unnecessary or premature. Several books on evolution and sociobiology carry such titles, and now here comes *Evolution: The Triumph of an Idea,* the companion book to a PBS television series. Having watched the full eight hours of the *Evolution* video, I understand why this book title was selected, but, just as the series does, I will postpone discussing this issue until the end.

Why has no one until now had the brilliant idea of putting together a series explicitly about evolution? It is such a delightful story to tell: how Darwin began developing his theory during his travels on the HMS *Beagle;* how, with his habitual intellectual honesty, he gave full attention to every possible objection; Darwin's receipt of Alfred Russel Wallace's manuscript, which led to a hasty session at the Linnean Society to declare the idea of evolution by natural selection; the resistance from paleontologist Richard Owen, English cleric Samuel Wilberforce, and others; the ultimately wide acceptance of the theory; and how the *Origin of Species* inspired generations of scientists to look at the world in an entirely new light (as all good theories do), which confirmed at every turn the soundness of its assumptions.

The television series opens with lots of acting: a youthful Charles Darwin debating new ideas with his drunkard brother, Erasmus (named after their grandfather, who a century earlier had proposed that "Organic Life beneath the shoreless waves,/Was born and nurs'd in Ocean's pearly caves"). Then we see Darwin lighting up with recognition and understanding as he reads British economist Thomas Malthus's work on the social struggle for resources. Another scene shows Darwin, with his favorite daughter, Annie, by his side, staring through a microscope at a barnacle as she playfully pronounces the animal's name as "Barney Ickle." Annie's death from scarlet fever, at the age of ten, is also depicted, with her father angrily and symbolically turning away from the church at her funeral. Her death, Darwin wrote, had robbed him of "the solace of our old age."

A range of topics in modern evolutionary biology are covered next. We see how random selection can transform evolution into an enemy—for example, when it turns viruses into lethal pathogens (here we see harrowing images of AIDS patients and of prisoners in Russia infected with multidrug-resistant tuberculosis). We also consider selection as the "friend" that shaped the evolution of the eye. This model organ is full of clues to random selection. The series does an excellent job of getting across that evolution has to deal with existing material, not only for the eye but also for quadrupedal locomotion and the genetics of fruit flies. The message is that the natural world is full of reused baggage. Truly "intelligent" design from scratch could have produced a much more effective eye—without a blind spot, say—but evolution has to work with the old to make the new. "Tinkering" is therefore a word frequently used by the eminent scientists interviewed in *Evolution.*

Evolution is as much about destruction as it is about creation. Thus, one episode in the series covers mass extinctions and the need to preserve biodiversity, while another looks at sexual reproduction, without which viruses

would freely attack species that are "sitting ducks" because of their lack of genetic diversity. I found these episodes most satisfying because they combine new thinking in evolutionary biology with the work of scientists who are collecting the corroborating evidence, such as in the testing of the Red Queen hypothesis (named for Lewis Carroll's character, who said to Alice, "Now, here, you see, it takes all the running you can do, to keep in the same place" —that is, a host population continually evolves to stay one step ahead of its parasites and pathogens).

The task of choosing which topics to include must have been almost impossible, given the project's scope. Evolution is such a dominant concept that it has become synonymous with the life sciences in general. Yet I do wonder why barely any attention is paid to certain controversies (such as sociobiology and punctuated equilibrium) and to some of the most exciting theoretical extensions (kin selection theory, for example, or the handicap principle), while much time is devoted to highly speculative ideas (the connection between our gossiping and other primates' grooming, human brain size as a product of males trying to impress females, cultural change mimicking genetic evolution). The narrative doesn't give viewers many clues to distinguish the tried-and-true from the half-baked. The readable companion book, expertly written by science writer Carl Zimmer, generally does a better job of sorting out what is serious science and what, at this point, is an idea whose triumph remains up in the air.

This brings me back to the word "triumph" in the book's title, which betrays a preoccupation with the adversaries of evolution. By paying less attention to the peculiarly North American tension between Biblical literalism and the life sciences, the series could have truly celebrated a magnificent idea that has won over essentially everyone in the world willing to listen to scientific arguments (including the pope). Science is a brutal process of holding ideas up against the light of data, and if one does so—as this series does with the theory of evolution—there is absolutely no reason to sound defensive about it. With overwhelming substantiation, theory has become fact. Facts don't "triumph"; they simply *are*.

In the last segment, we catch a glimpse of ongoing attempts at indoctrination by those who believe otherwise, such as a guy with hat and guitar jovially conducting a sing-along with a Christian audience, including many children: "I don't believe in evolution, I know creation is true/I believe that God above created me and you." Sing such lines a hundred times when you are young and, yes, you will be thrown into turmoil when first exposed to modern science. The struggle of some college students with issues that pit religion against the theory of evolution is painful to watch, because the conflict is wholly unnecessary. Evolution deals with how life arose; religion with how it is to be lived.

If *Time* can put a chimpanzee's face on its cover with the title "How Apes Became Human" (July 23, 2001), the idea of evolution has evidently become mainstream. It is time to treat it as such. This series presents its fascinating story in a lively yet responsible manner, bound to delight and inform.

Evolution, *a coproduction of the WGBH/NOVA Science Unit and Clear Blue Sky Productions, is a seven-part television series (PBS, September 24–27, 2001). The companion volume,* **Evolution: The Triumph of an Idea,** *is by Carl Zimmer (HarperCollins, 2001; $40).*

Frans B. M. de Waal is C. H. Candler Professor of Primate Behavior and Director of Living Links at Emory University in Atlanta. His latest book is The Ape and the Sushi Master: Cultural Reflections of a Primatologist *(Basic Books, 2001).*

nature.net

Follow a Fossil

By Robert Anderson

My five-year-old has informed me that he is, without question, going to be a paleontologist when he grows up. Not wanting to discourage him, I took him to see the Rancho La Brea Tar Pits in Los Angeles, where fossil collectors laboring away in Pit 91 were unavoidably smeared with black gooey tar and the air reeked of hydrocarbons. It was worse than a refinery. Although unperturbed by the working conditions, my son was disappointed to learn that the tar-pit remains represented a very recent slice of geologic time (as you will see if you visit www.tarpits.org) and held no chance of yielding dinosaurs.

I found a great Web site for him that reinforces the stark reality of paleontology: that while being a lot of fun, it is also very hard work. The Denver Museum of Nature and Science's "Follow a Fossil" (www.dmnh.org/denverbasin2/fossil) describes prospecting for fossilized ancient life-forms and the labor involved in transferring them from field site to museum.

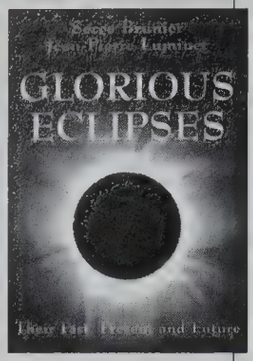
In the section on vertebrates, we track the path of a rather obscure Cretaceous turtle (they can't all be *T. rex*) from where it was dug up in North Dakota through its "jacketing," cleaning, casting, storage, and identification. Another section explores invertebrates—specifically, ammonites found in Colorado that are the size of manhole covers.

Will my son, still fixated on dinosaurs, become motivated to rough it in the field? I have yet to tell him about the job I once had sorting fossil plankton skeletons the size of sugar grains. I don't want to burst his bubble.

Robert Anderson is a freelance science writer living in Los Angeles.

CATER TO YOUR CURIOSITY

Glorious Eclipses
Their Past, Present and Future
Serge Brunier and Jean-Pierre Luminet



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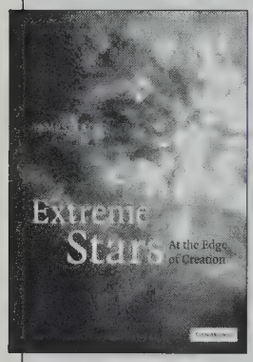

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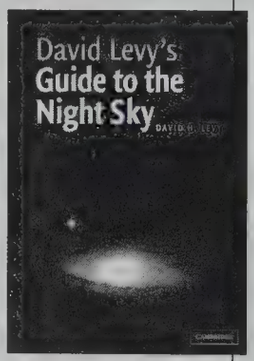

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BOOKSHELF

The Triumph of Sociobiology, *by John Alcock (Oxford University Press, 2001; $27.50)*
In 1975, ant expert E. O. Wilson published *Sociobiology: The New Synthesis,* a systematic study of the biological basis of all social behavior. Alcock, a biologist, looks at the ongoing debate sparked by Wilson's ideas and shows that they make sense in light of evolutionary theory.

Rock of Ages, Sands of Time, *paintings by Barbara Page, text by Warren Allmon (University of Chicago Press, 2001; $45)*
Page depicts a sampling of the earth's organisms at million-year intervals to represent evolutionary history from "the origin of macroscopic life on this planet [to] the recent conclusion of a millennium." Succinct essays by Allmon introduce readers to each geological period. Page's 544 contiguous panels will be installed in the new Museum of the Earth in Ithaca, New York, in 2002.

Wildlife Wars: My Fight to Save Africa's Natural Treasures, *by Richard Leakey and Virginia Morell (St. Martin's Press, 2001; $25.95)*
The views and voice of Leakey—physical paleoanthropologist, director of the Kenya Wildlife Service (1989–94), and advocate of African wildlife conservation—are captured here by Morell, a journalist who has relied on Leakey's notes and diaries and on her many discussions with him.

The Tangled Field: Barbara McClintock's Search for the Patterns of Genetic Control, *by Nathaniel C. Comfort (Harvard University Press, 2001; $37.50)*
This readable biography of one of the twentieth century's most important geneticists interweaves fact and insight about McClintock as both person and scientist. Her discovery of mobile genetic elements in corn and her efforts to resolve fundamental problems in biology (development, heredity, and evolution) make her, in Comfort's view, a rare visionary.

Uncle Tungsten, *by Oliver Sacks (Knopf, 2001; $25)*
"Many of my childhood memories are of metals: these seemed to exert a power on me from the start," neurologist Sacks writes at the beginning of his vivid memoir about growing up in wartime England and discovering the life of the mind.

PHOTOGRAPHY

AYUTTHAYA, THAILAND, 1998

Sacred Places, *by Kenro Izu (Arena Editions, 2001; $65)*

The World According to Pimm: A Scientist Audits the Earth, *by Stuart Pimm (McGraw-Hill, 2001; $24.95)*
In a book packed with sobering information, conservation biologist Pimm considers our global use and misuse of water and land and the wildly acceler-

ating rate of species extinction, yet he remains confident that good stewardship will save the planet.

The Northern Lights: The True Story of the Man Who Unlocked the Secrets of the Aurora Borealis, *by Lucy Jago (Knopf, 2001; $24)*
Explaining these colored arches, bands, and curtains in the night sky became the lifework of Norwegian scientist Kristian Birkeland, whose theories about the northern lights, electromagnetism, comets, and the sun were accepted by the scientific community only after his death in 1917.

Rowing to Latitude: Journeys Along the Arctic's Edge, *by Jill Fredston (North Point Press, 2001; $24)*
Be it storm, bear, or iceberg, nothing is predictable in Fredston's account of summering in the Arctic with her husband in a pair of oceangoing sculls (both work as avalanche experts in Alaska during the winter). One unusual discovery in Norway's Svalbard Islands was a bowhead whale hanging fifty feet above the water, its belly still embedded in the melting glacier that had encased it during the Little Ice Age (1300–1860).

Women of Discovery: A Celebration of Intrepid Women Who Explored the World, *by Milbry Polk and Mary Tiegreen (Clarkson Potter, 2001; $40)*
Here, packed with illustrations and photographs, are the stories of eighty-four visionaries, adventurers, artists, and scientists—from Chinese poet Lady Wen-chi, kidnapped by Mongol warriors circa A.D. 190, to U.S. geologist Louise Hose, a dedicated caver who has recently uncovered new life-forms in the sulfurous passageways of Mexico's Cueva de Villa Luz.

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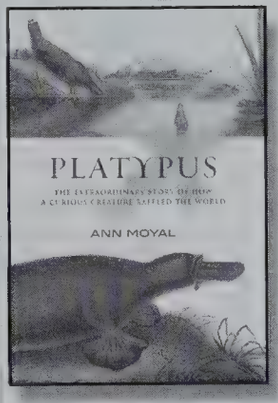

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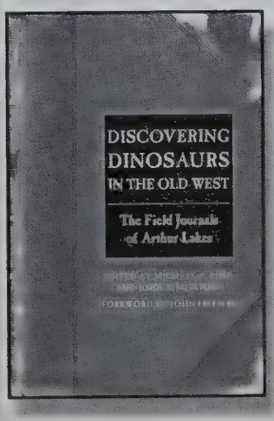

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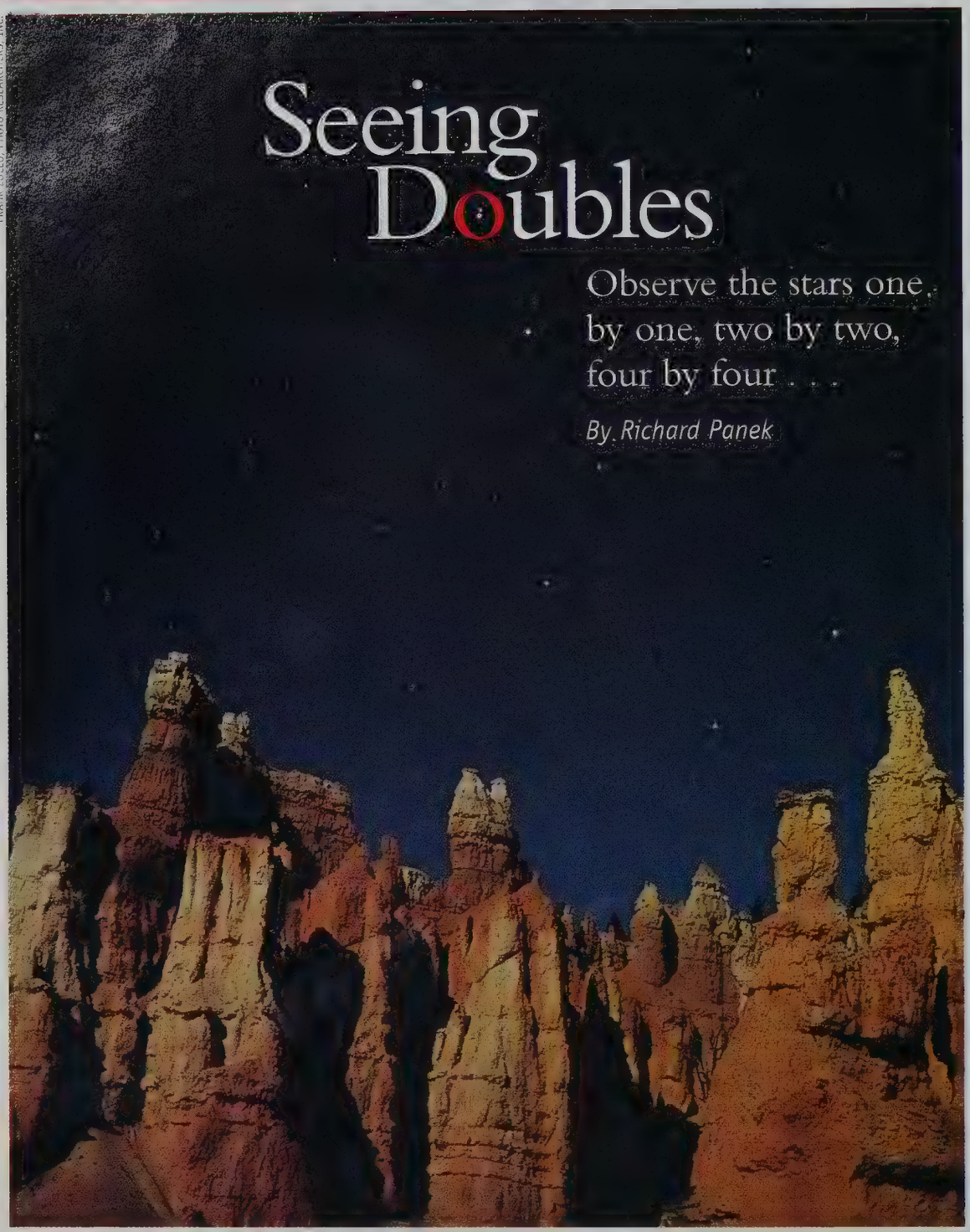

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Seeing Doubles

Observe the stars one by one, two by two, four by four . . .

By Richard Panek

At some time or other, you've probably found yourself staring up at the stars and marveling, "Look at all those points of light!" Maybe for emphasis you added an adjective: "Look at all those *individual* points of light!" If so, you were wrong.

Contrary to appearances, if not common sense, the majority of "stars" are not individual points. They're systems of multiple stars so far from Earth that to the naked eye, each system appears to be a single entity. The illusion is especially convincing because it reinforces an insidious prejudice, one so fundamental to the way we think about the universe that we might easily overlook it. In fact, for thousands of years, we did. Because we see a singleton, the Sun, in our daytime sky, we assume that the stars in our nighttime sky must be the same.

But the Sun is actually an exception. When British astronomer William Herschel undertook, in the late eighteenth century, the first comprehensive telescopic survey of stars, he started finding doubles everywhere. At first he figured that such pairs consisted of two stars vastly distant from each other but coincidentally lying along a single line of sight—a visual phenomenon we now call optical doubles. And some were. But over time, he observed that most were two stars interacting through their mutual gravitational attraction—*physical* doubles. Not only did this surprise Herschel, but it provided stunning support for the idea that Newton's theory of gravitation applied beyond our solar system—that it just might be universal, after all.

One especially prominent example—the second point of light from the end of the handle in the Big Dipper—provides a sort of history of our evolving understanding of double stars. This "star" is actually two stars, an optical double consisting of Mizar (the brighter star) and Alcor. (The pair are circled by the red "o" in the photograph at left.) From the earliest days of sky watching, the ability to perceive this optical double served as a test of eyesight among Arabs and Native Americans. But Mizar itself is not an individual star. Most standard sources credit Italian astronomer Giovanni Battista Riccioli with being, in 1650, the first to resolve Mizar (through a telescope) into Mizar A and Mizar B,

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though recent research indicates that the honor might belong to Benedetto Castelli and date back to 1617—less than a decade after the invention of the telescope. Either way, to Mizar goes the distinction of being the first telescopic binary.

Then in 1889, Harvard astronomer Edward C. Pickering examined the lines in the stars' spectra and found that one of the two, Mizar A, was itself a binary, thereby bestowing on it the distinction of being the first spectroscopic binary. Later analysis revealed the same to be true of Mizar B. A spectroscopic binary, by definition, should frustrate even the most powerful telescope, but in 1996 the Navy Prototype Optical Interferometer focused on the Mizar A binary—which, for the record, comprises Mizar Aa and Mizar Ab—and produced what was at the time the highest-resolution image in the history of optical astronomy.

From the earliest days of sky watching, the ability to perceive this optical double served as a test of eyesight among Arabs and Native Americans.

As should be apparent by now, the designation "binary" or "double" hardly does justice to the complexity of Mizar's system of stars. In such cases, astronomers instead use the term "multiple star system," though if they need to be specific they can invoke "triple," "quadruple," and so on.

In all its manifestations, however, Mizar lacks one important distinction that astronomers make when it comes to star systems: it is not an "eclipsing binary." This term refers to a pair of stars, one of which has an orbit that takes it on a path directly between the other star and Earth, producing a visible variation in the overall brightness of the pair. In 1669, Italian astronomer Geminiano Montanari discovered just such a peculiar and periodic variation in the star Algol (not to be confused with Mizar's companion, Alcor), in the constellation Perseus, and today eclipsing binaries are sometimes called Algol-type variable stars.

This month the Big Dipper is low on the northern horizon in the first hours after nightfall. If the sky is calm and clear and your eyesight is good, you should be able to see both Mizar and Alcor on your own, though you'll definitely need the help of a telescope or binoculars to distinguish Mizar A from Mizar B. Meanwhile, the eclipsing binary Algol will be rising in the northeast at nightfall and reaching its zenith at about 3:00 A.M. Its companion, however, will be evident only through a sudden dip in brightness for several hours every 2.87 days, when Algol drops from magnitude +2.1 to +3.4. (The specific times during October—or any other month—when Algol experiences this variation can be found on *Sky and Telescope*'s Web site at www.skypub.com/sights/variables/algol.html.)

And let's not lose sight of Mizar's optical neighbor, Alcor. Yes, it's a binary, too, but of the spectroscopic type, which means that you won't be able to distinguish its two component stars even with the help of a telescope. Nonetheless, it's worth at least a token glance, if only in honor of its ancient Arabic name, Suha, whose English translation could apply equally well to so many of those other seemingly individual points of light up there: "the overlooked one."

Richard Panek's latest book, The Invisible Century: Einstein, Freud, and Our Search for Hidden Universes, *will be published next year by Viking.*

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THE SKY IN OCTOBER

By Joe Rao

Mercury reaches inferior conjunction (between Earth and the Sun) on October 14, but in the following two weeks it zooms up and away from the eastern horizon to put on its best morning show of the year. Beginning on the 20th, the planet emerges from the bright morning twilight 9° below and to the left of Venus. Each morning thereafter, Mercury moves a couple of degrees closer to Venus, brightening noticeably. Between October 28 and November 7, Mercury and Venus are less than 1° apart, and both are plainly visible. Mercury is at its greatest western elongation on October 29, reaching an unusually bright magnitude of -0.5; situated 19° above the eastern horizon at sunrise, it lies just 0.6° to the left of Venus.

Venus begins the month by rising, lustrous, in the east-southeast about one and a half to two hours before sunrise. It then sinks a little with each passing week. On the morning of the 15th, the planet rests just above and to the right of the Moon. In the final days of October, binocular users may spy the first-magnitude star Spica emerging from the dawn glow well below Venus and its closest dancing partner of the month, Mercury.

Mars moves out of Sagittarius and into Capricornus late in the month. At dusk, the planet is visible low in the south-southwest, setting more than four hours later. Mars starts October at magnitude -0.4 (a bit brighter than the similarly-hued star Arcturus), but by the end of the month, as Mars continues to recede from Earth, it slips to magnitude +0.1. Back in June, Mars came within 41.8 million miles of Earth; by October 31, it's 99.3 million miles away.

Jupiter rises at about midnight local daylight time at the beginning of October. Two hours later, it is the brightest starlike object in the sky, visible at about 20° above the eastern horizon. By the 31st, it rises close to 9:00 P.M. local standard time. Jupiter currently resides in the feet of Gemini, not far from the upraised club of Orion. In midnorthern latitudes, observers can see Jupiter shining regally near the zenith toward dawn, the highest position the planet has reached since 1990. The Moon passes near Jupiter late on the night of October 9–10.

Saturn, in Taurus, rises in the east-northeast a little more than three hours after sunset on October 1 and about two hours after sunset on the 31st. It can be found about 6° northeast of the first-magnitude star Aldebaran all month. By dawn, Saturn is high in the west-southwestern sky. No one with a telescope should resist the temptation to turn it on glimmering Saturn. You should readily be able to see the planet's rings in all their icy elegance and perhaps a few of Saturn's larger moons as well. A gibbous Moon hovers near Saturn and Aldebaran late on the night of October 6–7.

The Moon is full—a harvest moon—on October 2 at 9:49 A.M. Last quarter Moon falls on the 10th at 12:20 A.M. The Moon is new on October 16 at 3:23 P.M., and first quarter comes on October 23 at 10:58 P.M.

Eastern Standard Time goes into effect for the United States (except for Arizona, Hawaii, and Indiana) on October 28, the last Sunday in the month. Officially, on this date the hour from 1:00 to 2:00 A.M. is repeated, so turn your clocks back one hour anytime thereafter.

Unless otherwise noted, all times are given in Eastern Daylight Time.

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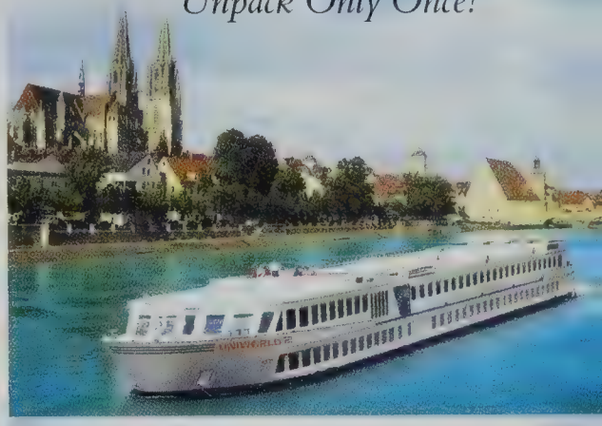

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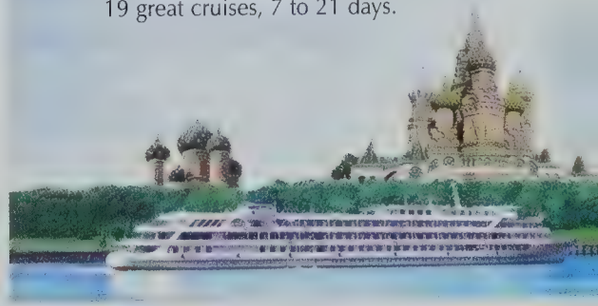

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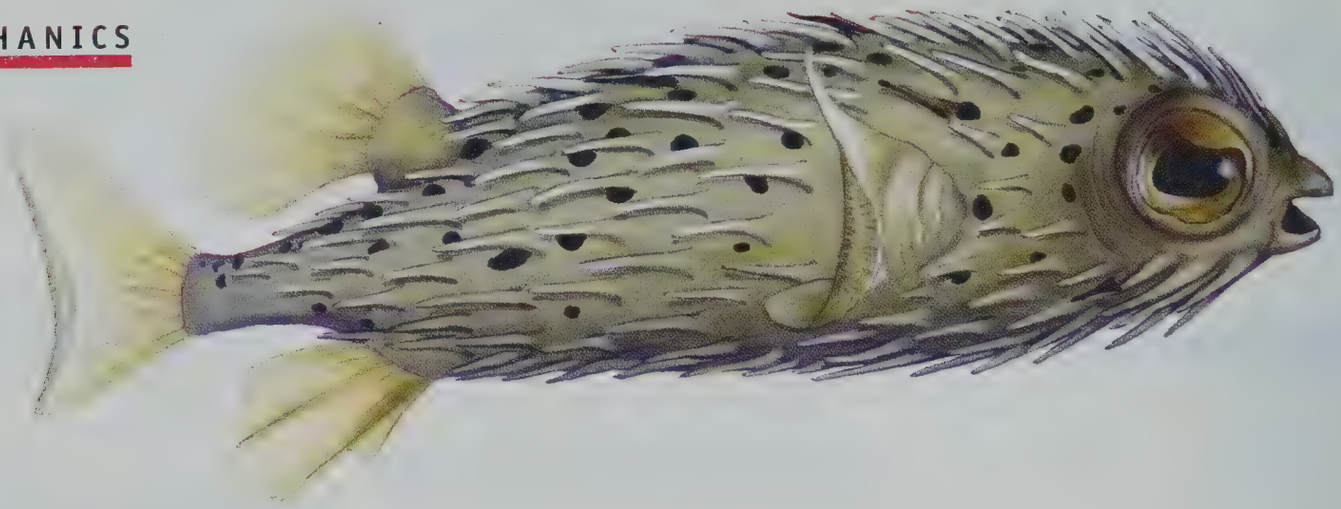


A Fish Story

The spiny puffer's means of defense is hard to swallow.

Story by Adam Summers ~
Illustrations by Sally J. Bensusen

When alarmed, some toads and snakes puff themselves up impressively. Hedgehogs, porcupines, and some Old World salamanders sport protective spines. But only the spiny puffer *(Diodon holocanthus)* combines inflation and pointy spikes in one spectacular defense mechanism.

Also called balloonfish, spiny puffers belong to the Tetraodontiformes, an order of fishes known for their strange structures and odd behaviors. The boxfish, for example, is an aquatic tank with two bony skeletons, one on the inside to support its innards and one on the outside to deter predators. And the massive, tailless ocean sunfish, another relative, is essentially a huge disk—consisting of head and torso—pushed along by a couple of fins.

Compared with creatures like these, the spiny puffer seems relatively normal when relaxed. But when threatened, the puffer undergoes a remarkable transformation, its body swelling until the fish is three times its usual size and has become a rigid, near-perfect sphere covered in spiky armor—not a good design for swimming but decidedly discouraging to attackers.

Beth Brainerd, of the University of Massachusetts, studies the biomechanical tricks the puffer uses to accomplish its swell feat. A more accurate name for this fish would be "pumper," because it inflates not by puffing itself up but by pumping water into its stomach (which has ceded its digestive function entirely to the intestine). The stomach expands to nearly a hundred times its original volume, an astonishing increase made possible by the stomach's being pleated, like a skirt. An amazing amount of material can be hidden away in pleats. Consider that a typical Scottish kilt is made from eight yards of tartan fabric, whereas the typical Scotsman is only about a yard around. And the pleats of a puffer's stomach are more extensive than those of a kilt: inside the largest pleats (each of which is about three millimeters wide) are smaller folds, with yet smaller folds inside each one, and so on, down to pleats so tiny that they can be seen only through a microscope.

As the puffer fills with water, the fish's spine, already slightly curved, bends into an upside-down U shape, and the liver, intestines, and other internal organs become squeezed between the fish's backbone and its rapidly expanding stomach.

Meanwhile, the fish's skin is pushed out, obscuring most of the puffer's features. Only the mouth—a cartoonish orifice containing heavy, crushing plates capable of pinching a human finger to the bone—remains unaffected.

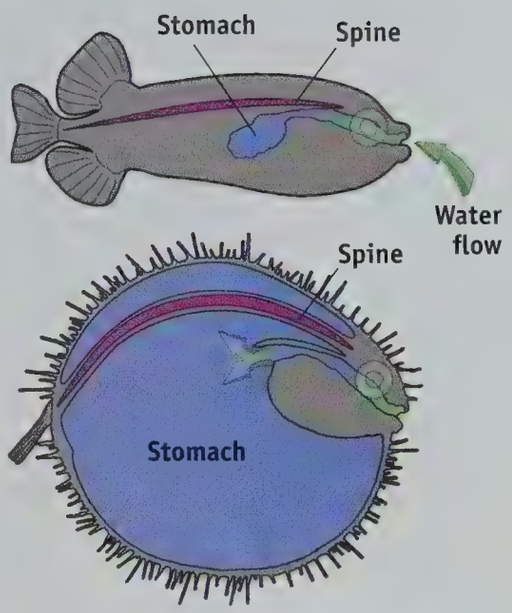
The skin of a fully inflated puffer is stretched to one and a half times its resting length. But while the skin's elasticity accounts for the change in the volume of the fish, stiffness and strength are required to turn the creature into a rigid ball. For this the puffer again turns to pleats. Brainerd discovered that the spiny puffer's skin consists of two layers—a thin, elastic outer layer and a fibrous inner layer. This inner layer of skin is pleated and, when extended, quite stiff. So why bother with the outer elastic layer? To answer that, one need only picture a deflated, pleated puffer—it would be a rumpled, hydrodynamically impaired laughingstock.

The skin also helps deploy the puffer's armor. The scales of this fish have been modified into slender spikes, each on a tripod-shaped, bony base embedded in the skin. Normally the tripod lies on its side, with the spike flat against the skin, pointing backward. But when the fish puffs up, the stretched skin pulls two of the

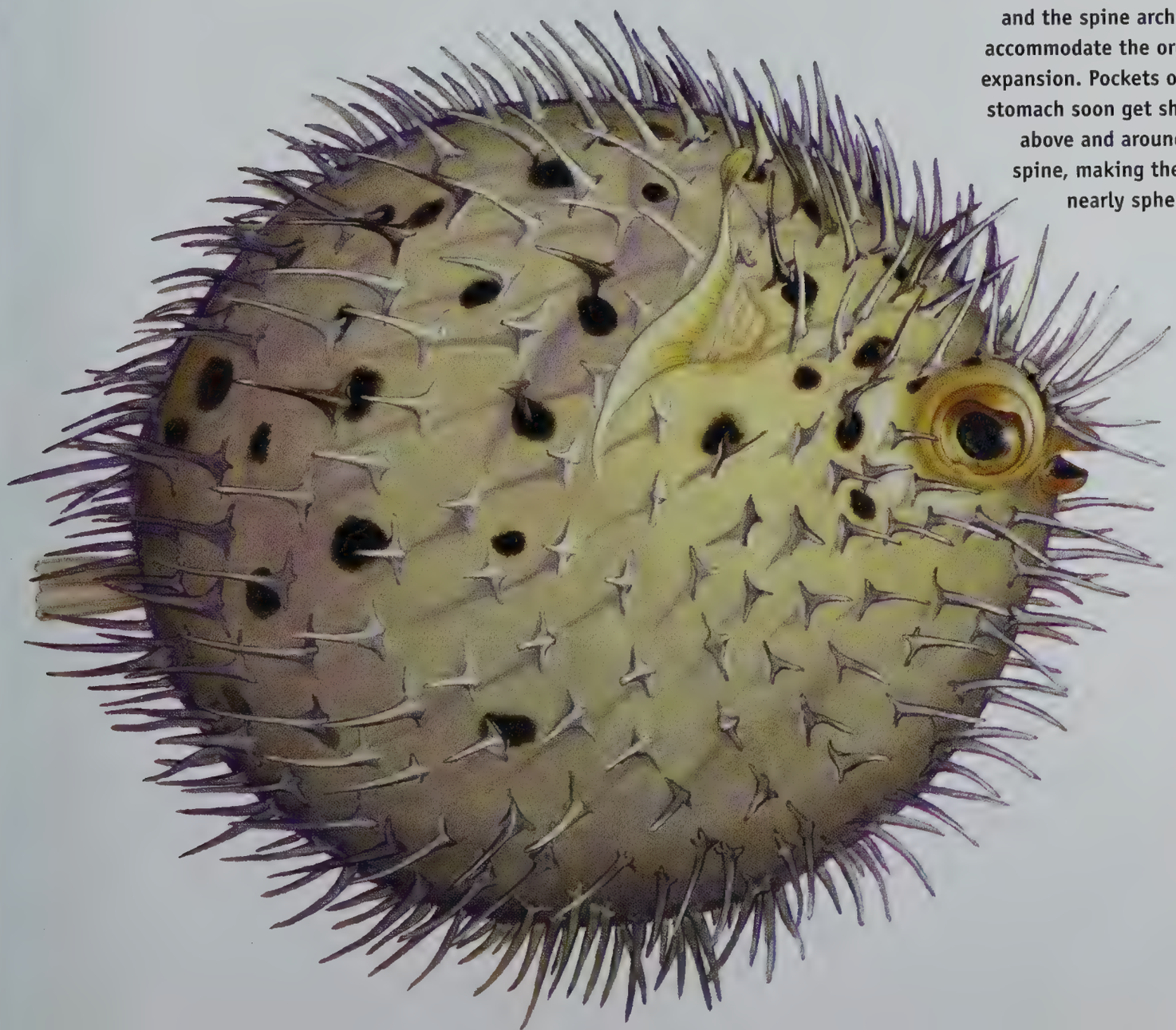
tripod's legs backward and one leg forward, snapping the spike upright. The three legs provide a secure base that blunts the force of anything pushing against the spike's sharp tip.

Peter Wainwright, an evolutionary physiologist at the University of California, Davis, has found clues to the origins of puffing in the triggerfish *Balistes capriscus,* a close relative of the spiny puffer. Triggerfishes feed on unusually well defended prey: spiny sea urchins. The fish's usual modus operandi is to shoot jets of water at the urchin's side until it rolls over, exposing its unprotected "belly" (actually its mouth, with which it grazes on the seafloor). The triggerfish uses the same muscles to blow water out of the stomach that the spiny puffer uses to pump water into it. Both fish first expand their mouths to draw in water, but the puffer then pumps the water into its stomach, while the triggerfish opens its mouth and pumps the water back out. Natural selection may have taken advantage of a pumping mechanism that had evolved for disabling prey—turning it inward and transforming it into a mechanism for self-inflation.

Adam Summers is an assistant professor of ecology and evolutionary biology at the University of California, Irvine.



As a spiny puffer pumps water into its stomach, the stomach inflates and the spine arches to accommodate the organ's expansion. Pockets of the stomach soon get shoved above and around the spine, making the fish nearly spherical.



THE NATURAL MOMENT

Bat Boy

Photograph by **Theo Allofs**

The world's 925 or so species of bats fall into two suborders. In the Americas, we are most familiar with the larger group, whose members are small and employ echolocation to catch flying insects. The other suborder comprises the largest-bodied flying mammals, including flying foxes. All strictly plant eaters, the sixty kinds of flying foxes are found mainly in India, mainland Southeast Asia, the islands of Indonesia, and Australia. Instead of using sonar when foraging at night, they rely on their excellent vision to find fruits and blossoms. In Australia, hundreds of thousands of flying foxes, often members of several species, congregate daily at arboreal "bat camps." After hanging upside down all day—squawking, grooming, and nursing their young—they take wing at night to seek food.

This male little red flying fox ("little" is part of its common name) is grooming its wings while hanging among hundreds of other bats in a eucalyptus tree near Brisbane, on Australia's east coast. Formerly dependent on the once-widespread eucalyptus forests, flying foxes now settle near farms and urban areas, where they incur the wrath and vengeance of farmers and homeowners by eating fruit from gardens and orchards.

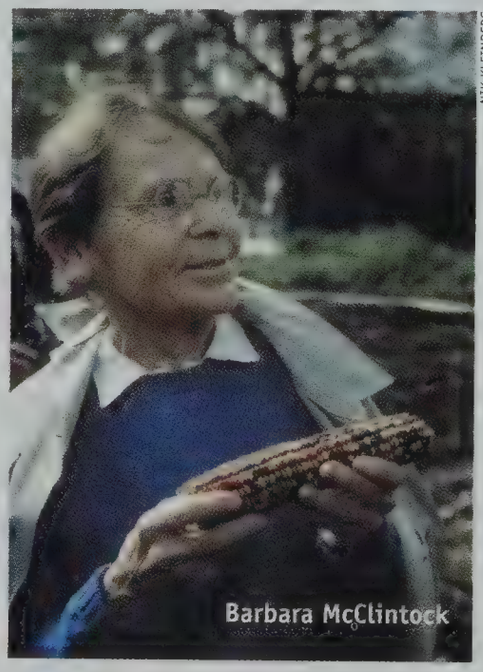
As the only mammals capable of sustained flight, bats rely on their semitransparent wings, composed of two layers of hairless skin stretched between the bones of their elongated forelimbs and those of their short hind limbs. Licking the wings is part of a daily routine. While grooming, the male flying fox keeps his genitals exposed, indicating to nearby females that he is receptive to mating. When his wings are spotless, he will coat them with an oily substance (produced by glands in his nose) that helps keep the membranes flexible and waterproof.—*Richard Milner*

ENDPAPER

"Suddenly you know the answer."

By Nathaniel C. Comfort

Barbara McClintock, the great geneticist of maize, was so smart she could seem mystical. But her power to solve complex genetic problems was not supernatural, only a matter of speed. In a process she called integration, McClintock got "signals" from her subconscious: "I cannot tell you necessarily where they come from, but the whole thing is solved suddenly."



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This sort of experience seems to be reported most often by mathematicians and physicists. The most famous integrator of all was Albert Einstein. He worked on problems, he once said, by playing with "certain signs and more or less clear images which can be voluntarily reproduced and combined." Some elements were "of visual and some of muscular type. Conventional words or other signs have to be sought for laboriously only in a secondary stage." Einstein said he reached his theory of relativity by imagining he was riding a light wave, and then looking around and describing what he saw.

For McClintock, the solution came too fast for pictures: "It's faster than I can recognize. Suddenly everything seems clear. Then you are able to put it in steps, 1, 2, 3, 4, and tell somebody about it and it seems perfectly logical. But that's not how it's arrived at; it's arrived at in some complex way that I have no way of stating. Suddenly you know the answer." When McClintock could not solve a problem, she said it was because she had not "oriented" herself properly to see the relationships among the pieces of her puzzle. Once oriented, she maintained, "I could integrate whatever I saw immediately."

Srinivasa Ramanujan, the self-taught Indian number theorist discovered by English mathematician G. H. Hardy, produced fantastic conjectures. Hardy then worked with him to derive formal proofs. Ramanujan was said to be "personal friends" with every positive integer, producing spontaneous observations—for example, that 1,729 is the smallest number expressible as the sum of two cubes in two different ways. Of John Nash, the creator of game theory, Sylvia Nasar (his biographer) observed, "Not very long after he started thinking about a problem, he would have just a very clear vision of where the solution lay. And he wouldn't know how to get to it and it might take a year or two to get there, but he had this vision." Physicist Richard Feynman integrated, too. His colleague Murray Gell-Mann once described the Feynman problem-solving method this way: "You write down the problem. You think very hard. Then you write down the answer."

McClintock described integration as a form of computation, a rational, rapid process of working out connections and logical steps. Her ability appeared especially remarkable when she used it to solve problems that other scientists had been puzzling over for months. As a young scientist at Cornell University, she was part of an extraordinary group of corn geneticists. In about 1930, Charles Burnham, another member of the group, was studying a trait with a bizarre pattern of inheritance. McClintock got hooked on the puzzle. Quite "disturbed" by the problem one day, she said, "I left the field, which was down in a hollow, and I walked up to my laboratory and I sat in my laboratory for about thirty minutes. Just sat there thinking about it, and I suddenly jumped up and ran down to the field. I was at the top of the field and everybody was down at the bottom, and I was saying, 'Eureka, eureka, eureka, I have it!'" The pattern, she realized, could result from the presence of an extra chromosome. When she joined the others, Marcus Rhoades, another colleague, said to her, "Prove it." Only then did she sit down with a brown paper bag and a pencil and sketch out her solution. She was right.

Integration for McClintock was an internal process of self-control and awareness. In explaining how one got into the integrating frame of mind, she could only repeat, "You do something with yourself. You do something with yourself."

Nathaniel C. Comfort is deputy director of the Center for History of Recent Science, in the Department of History at George Washington University.

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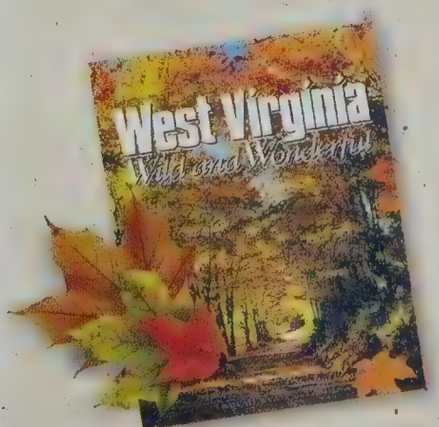

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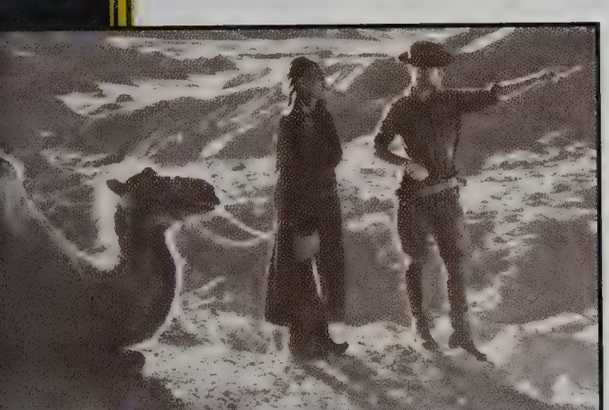

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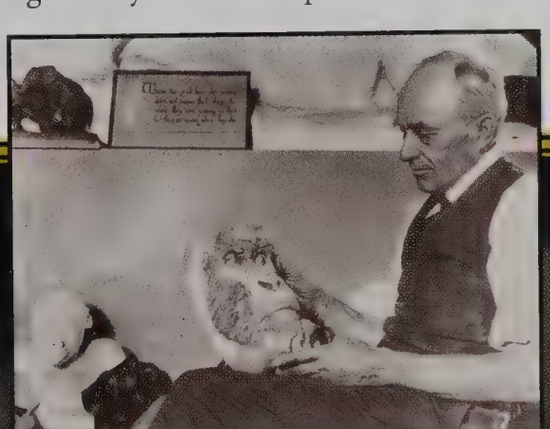

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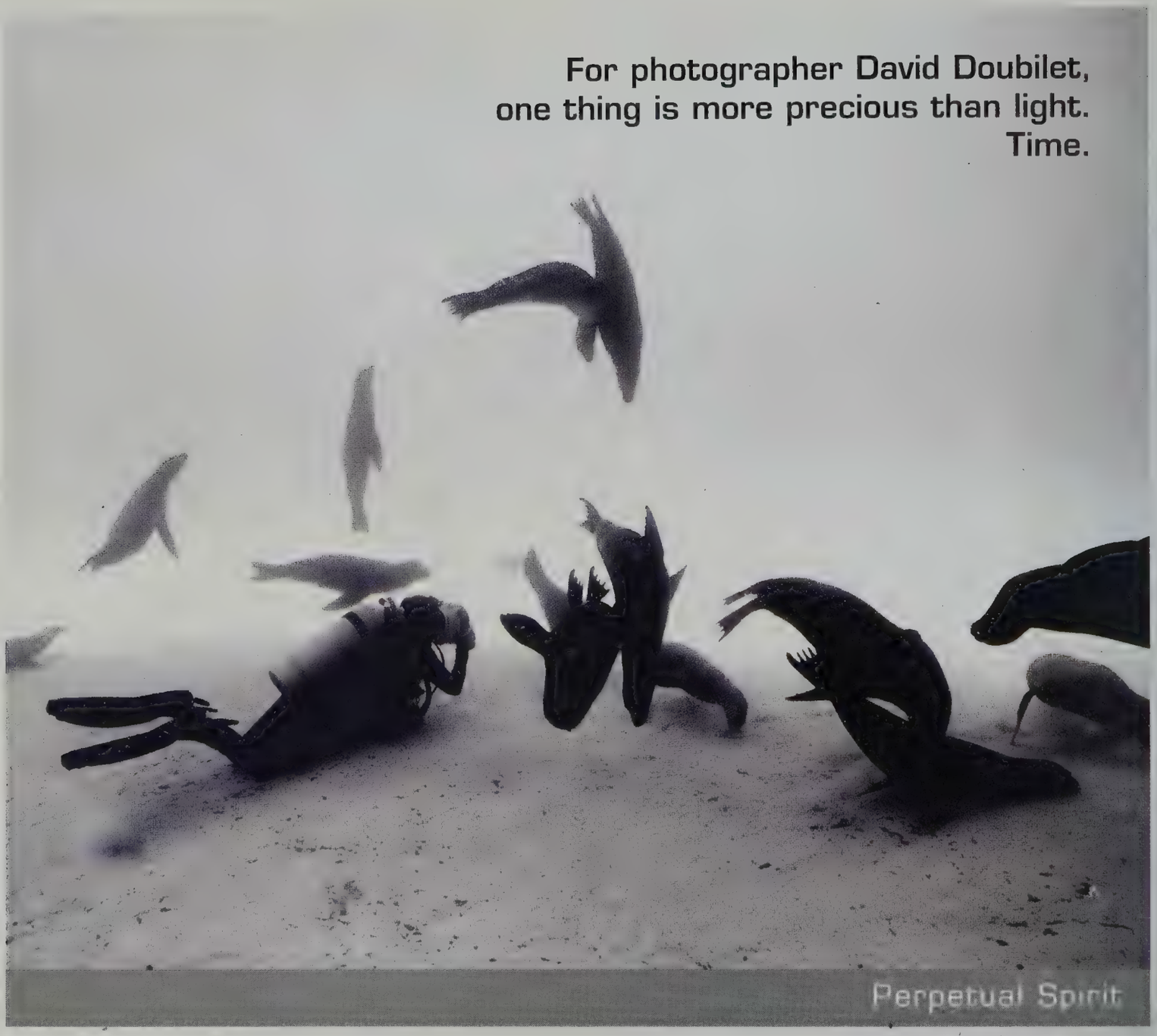
For photographer David Doubilet, one thing is more precious than light. Time.



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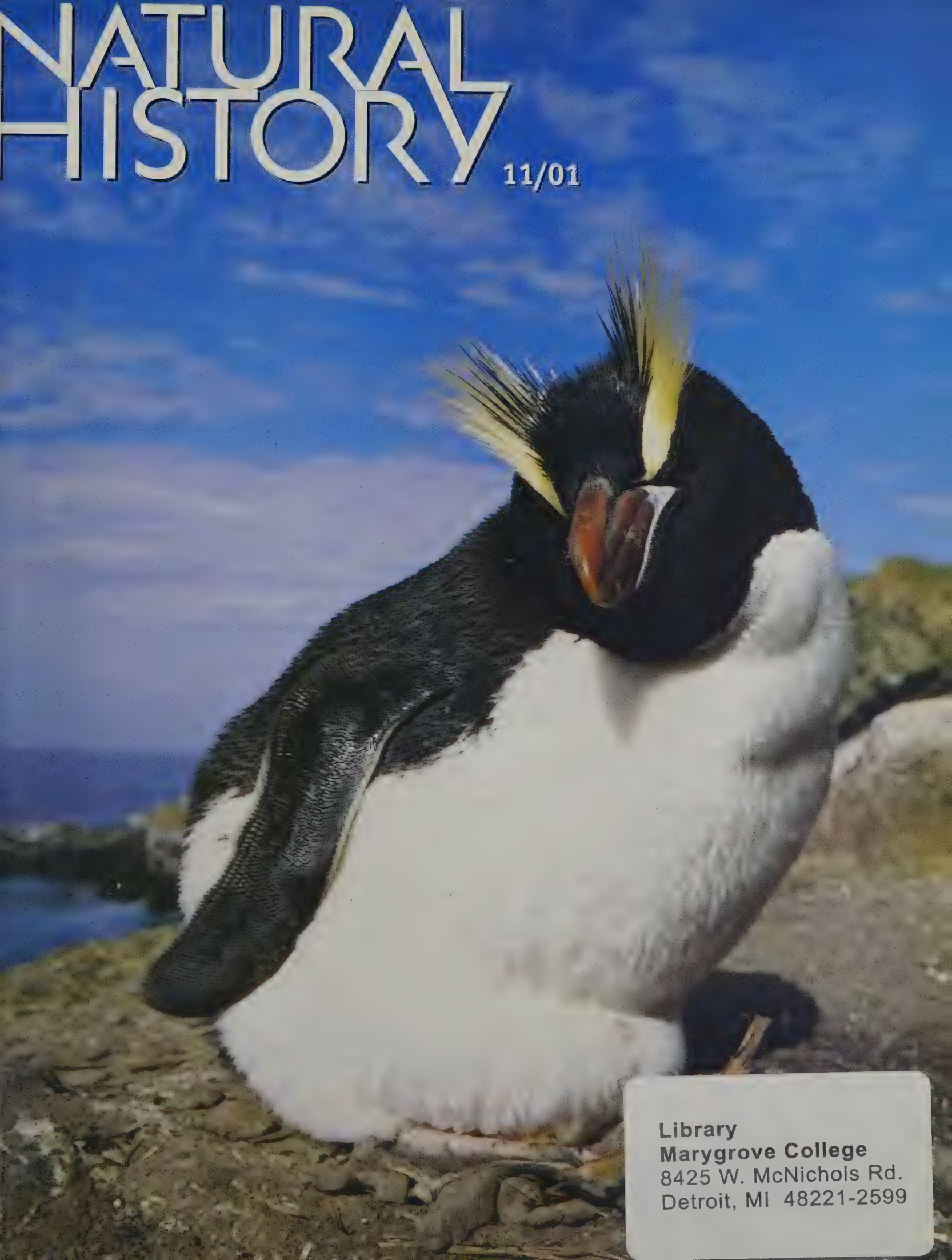

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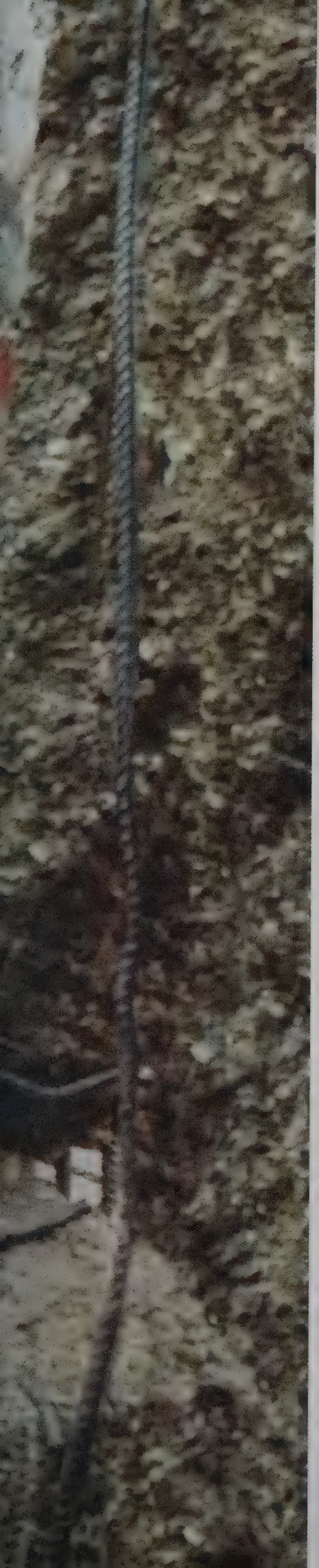

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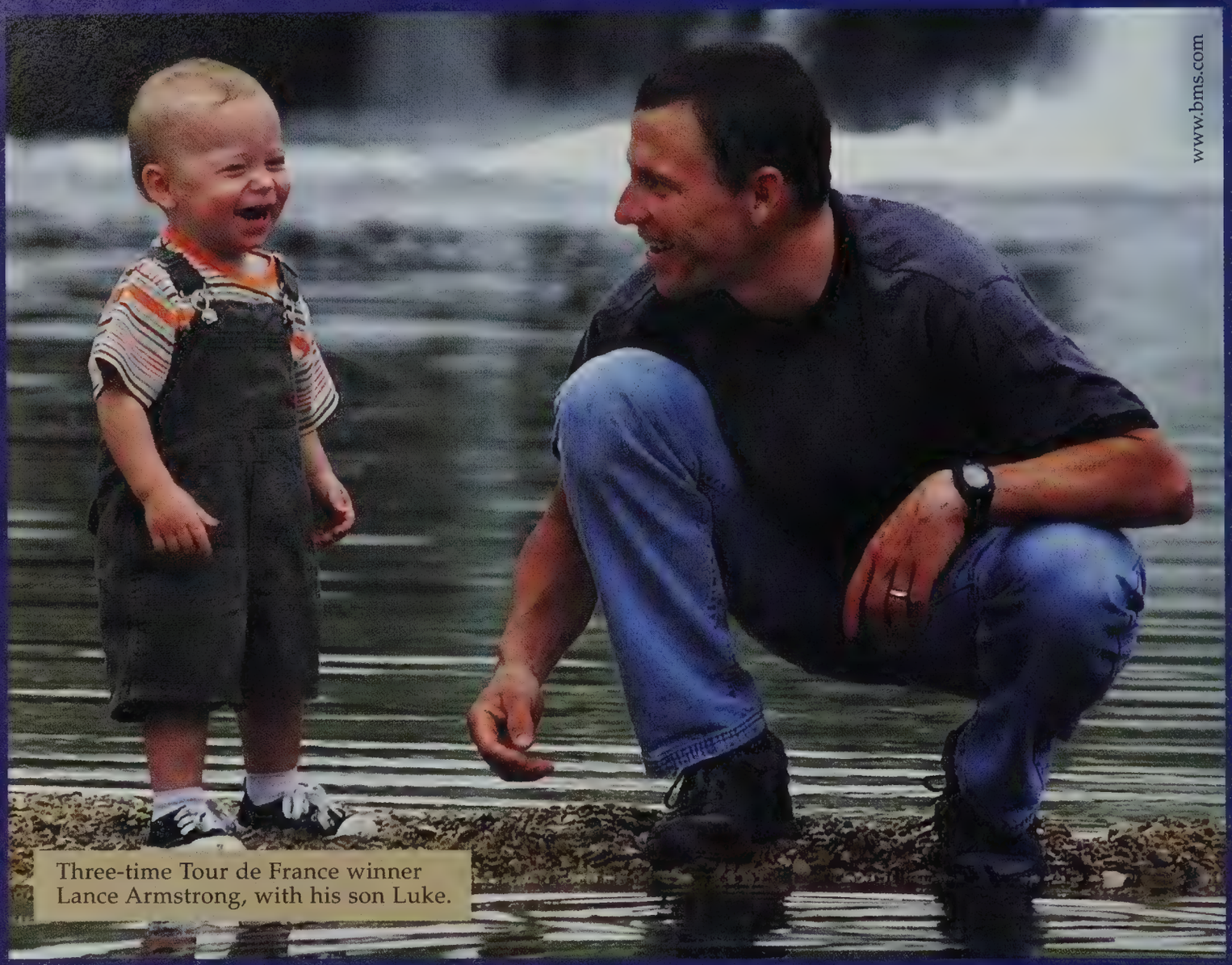

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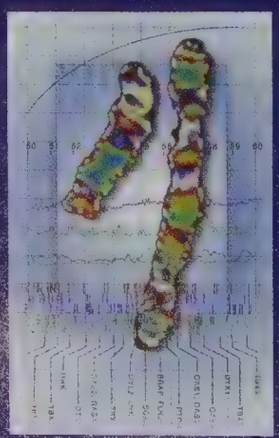
Three-time Tour de France winner Lance Armstrong, with his son Luke.



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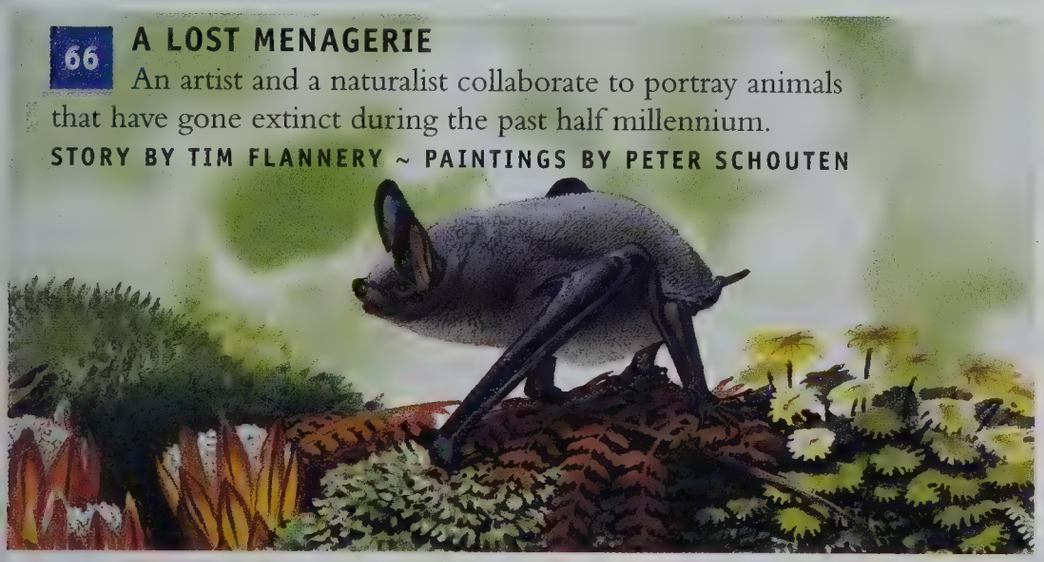

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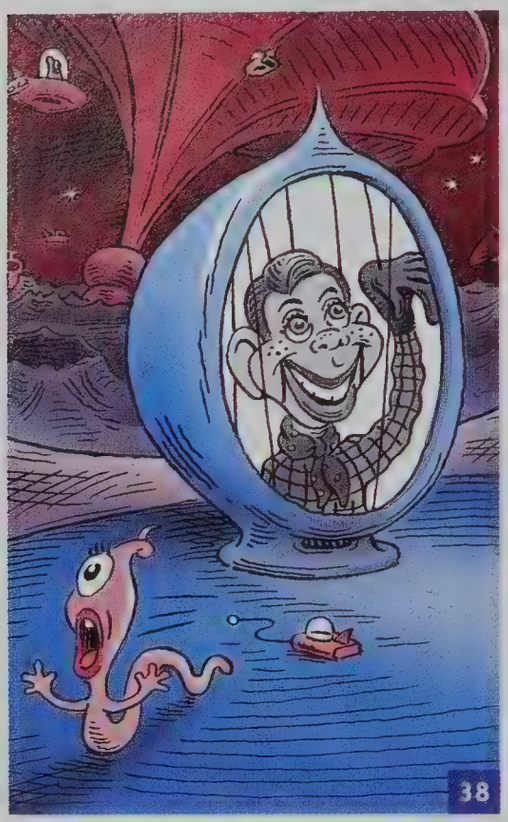

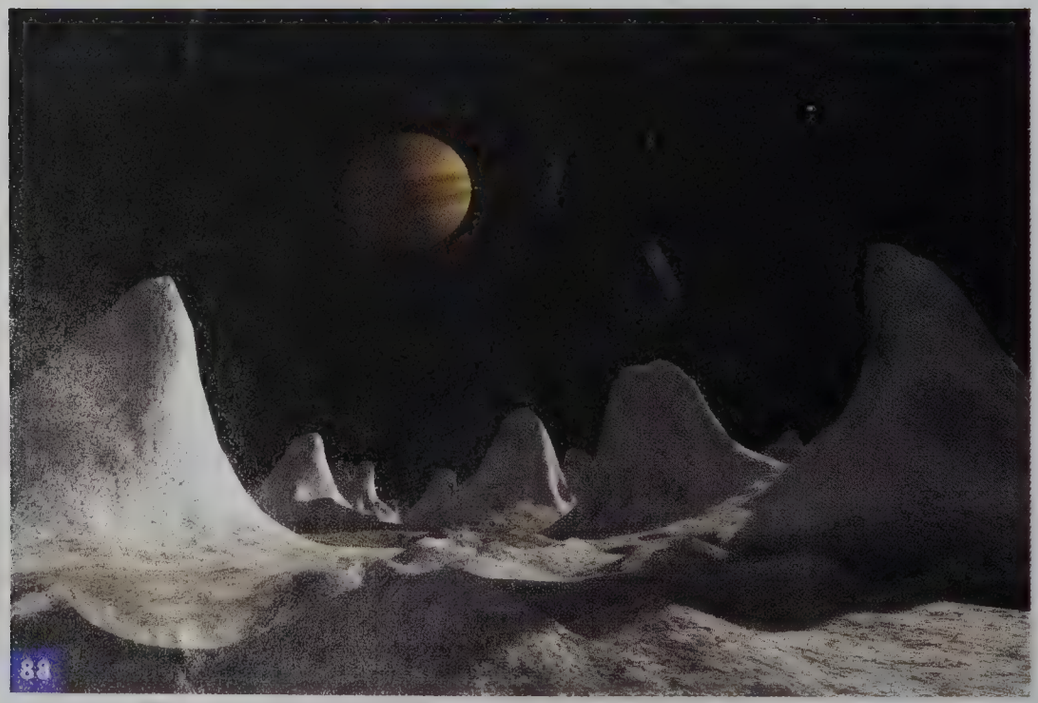

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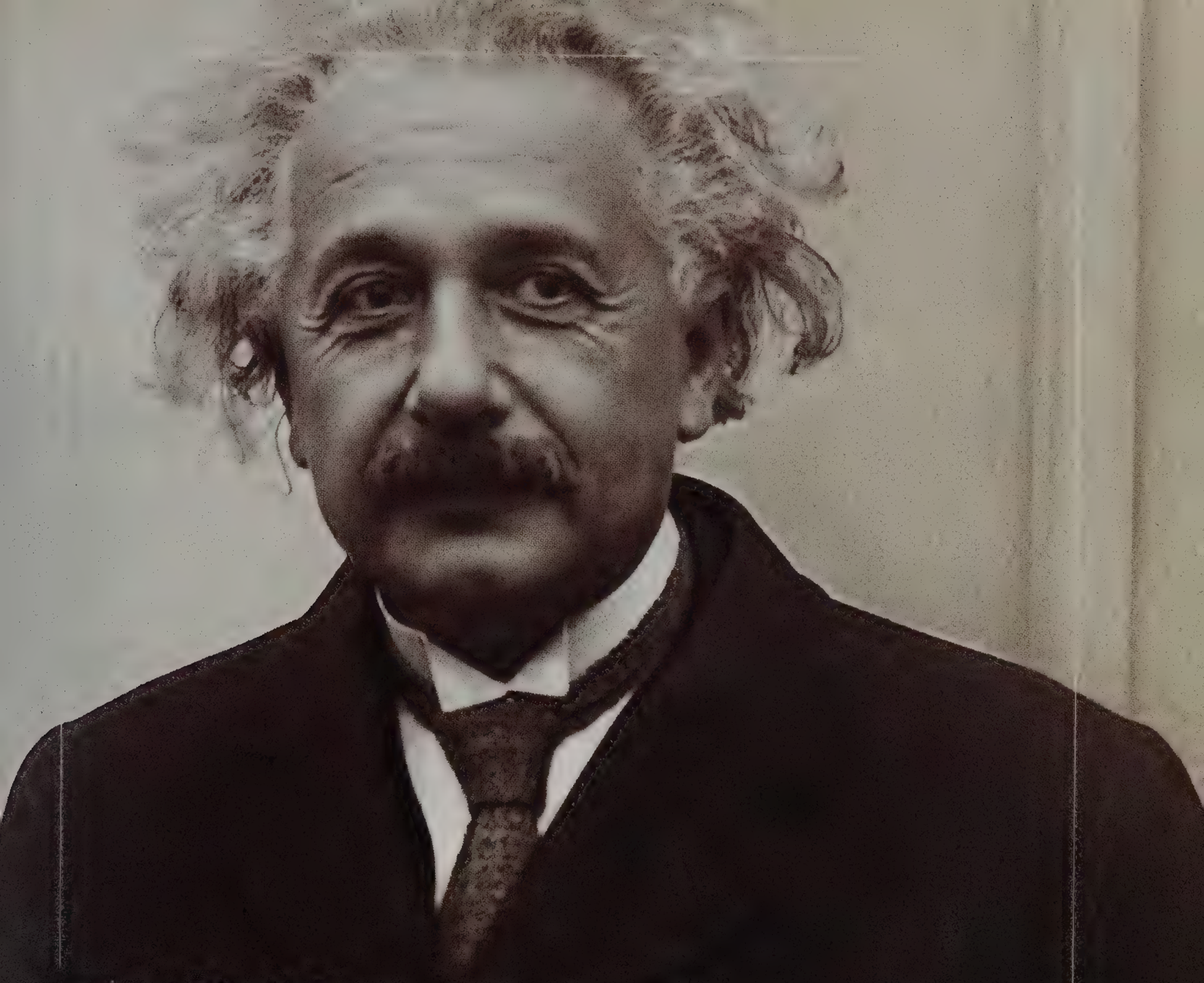

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UP FRONT

A Late Summer Day

"Last autumn the wild geese flew day after day across the path of the shells."
—Erich Maria Remarque, *All Quiet on the Western Front*

The American Museum of Natural History, where our offices are situated, is a hundred or so blocks north of the World Trade Center. On the bright, clear morning of September 11, a few members of the magazine's staff, on their way here from downtown and from Brooklyn, witnessed an attack that came quite literally out of the blue to demolish thousands of individual lives.

Neil deGrasse Tyson, director of the Museum's Rose Center for Earth and Space and author of our monthly column "Universe," is a member of the magazine family who lives in lower Manhattan. He bore precise, but not dispassionate, witness to the events of September 11 in an e-mail message sent to family and friends the next morning. Here is part of that message:

> *As more and more and more and more and more emergency vehicles descended . . . I hear a second explosion in WTC 2, then a loud, low frequency rumble that precipitates the unthinkable—a collapse of all the floors above the point of explosion. First the top surface, containing the helipad, tips sideways in full view. Then the upper floors fall straight down in a demolition-style implosion, taking all lower floors with it, even those below the point of the explosion. A dense, thick dust cloud rises up in its place, which rapidly pours through the warren of streets that cross lower Manhattan. I close all our windows and blinds. As the dust cloud engulfs my building, an eerie darkness surrounded us—the kind of darkness you experience before a severe thunderstorm. . . .*
>
> *I will never be the same after yesterday, in ways that I cannot foresee. . . . How naïve I was to believe that the world is fundamentally different from that of our ancestors, whose lives were changed by bearing witness to the twentieth century's vilest acts of war.*

Three weeks later, as the magazine goes to press, another spell of warm, bright weather temporarily envelops the city. From our balcony, we can see the occasional flock of birds moving south, and a security guard here told me that some of them are pausing to feed in the small park in front of the Planetarium. We are left to mourn, to carry on, to try to grasp what happened—and to look to the best of human science, anthropology, economics, history, literature, and philosophy to tell us why our species is capable of such things.

— Ellen Goldensohn

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LETTERS

Going Lightly

This hardly seems the time to be lighthearted, but I would like to comment on Neil deGrasse Tyson's amusing (and interesting) "Universe" article entitled "By Any Other Name" (7/01–8/01). I am a lifelong amateur astronomer and sometime philosopher of science, but I had never consciously taken notice of the curious fact highlighted by Tyson: that astronomical nomenclature is user friendly.

May I suggest an even simpler and better term for what he says astronomers call dark energy (the force now held accountable for the acceleration of the expansion of the universe)? I propose "levity." I think this would serve as an apt counterweight to its opposite, that heavy term "gravity."

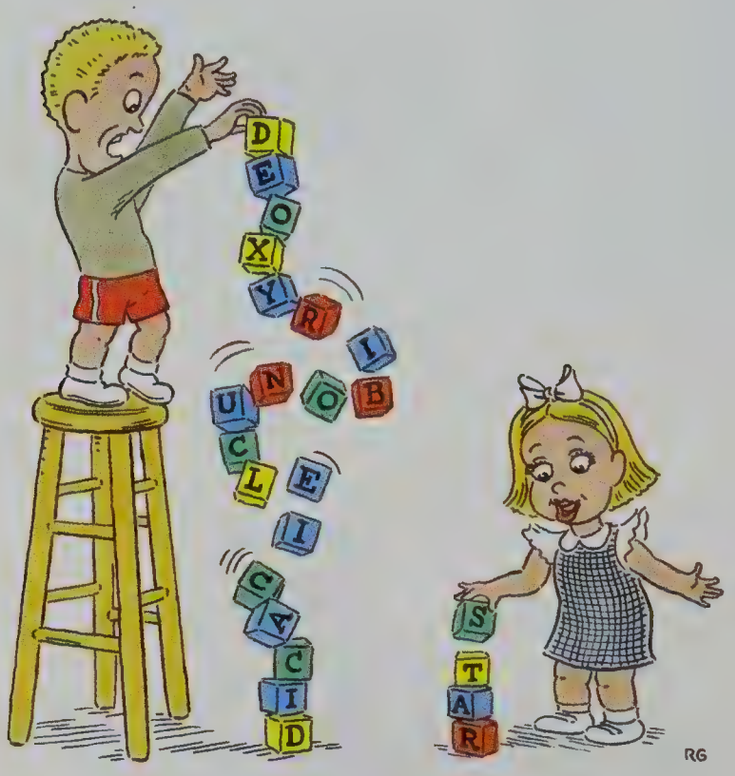
Joel Marks
West Haven, Connecticut

Speed Kills

I am writing to correct one of the statements in the note about eagles and trains that appeared in the "In Sum" column of 9/01. It is true that trains hit and kill eagles on the tracks between New York and Montreal, but not at 125 miles per hour. At present the only trains running that fast are traveling the Northeast Corridor, between Washington, D.C., and Boston.

Francis Mac Dowell
White Lake, New York

THE EDITORS REPLY: Our note was unclear; the original study mentioned an increase in bald eagle fatalities along the Hudson Valley of New York State but did not refer to any particular rail line when it cited the high velocities. According to Jerry Shook, of the New York State Department of Transportation, passenger trains on Amtrak's Empire Corridor, between New York and Albany/Schenectady, can reach 110 miles per hour, depending on the location and the track-signaling system in place. There are plans to increase the speed to 125 miles per hour as soon as tracks are upgraded to accommodate that speed. From Albany/Schenectady north to Montreal (on the Canadian Pacific Railway's main line), train speeds are considerably slower, reaching 70 miles per hour at a few points but mostly in the range of 50 to 60.



ROBERT GROSSMAN

"Bulletproof T-shirts, anyone?"

I have a question regarding the last sentence in Adam Summers's "Biomechanics" article on the properties of silk ("Got Silk?" 7/01–8/01). Is it true that twelfth-century Mongol warriors wore silk shirts that prevented enemy arrows from penetrating their bodies?

Daniel Marcus
Armonk, New York

THE EDITORS REPLY: According to Central Asia scholar Morris Rossabi, Daniel Marcus is absolutely right. Rossabi recommends a book by James Chambers, *The Devil's Horsemen: The Mongol Invasion of Europe,* for more information. Chambers writes: "The heavy cavalry wore a coat of mail with a cuirass made of oxhide or iron scales covered in leather, and the light cavalry wore either a cuirass of lacquered leather strips or else a quilted *kalat* [tunic] and no armour at all. Next to his skin every soldier was required to wear a long, loose undershirt made from raw silk. An arrow might pierce his armour and penetrate his body, but it would usually fail to cut through the silk and would instead carry the silk with it into the wound. . . . [B]y gently lifting the twisted silk around the wound, the Mongols could draw the arrow out, turning its head along the same route as the one by which it had entered, and thus leave the hole as neat and small as possible. . . . [T]he wound was not always as clean as the physicians might have hoped: . . . soldiers often kept on their shirts until they began to rot."

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Elk Grove, California

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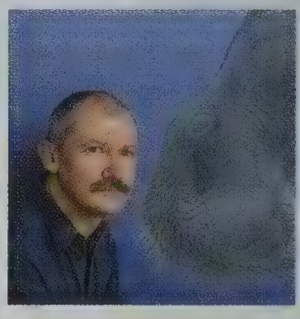
CONTRIBUTORS

Braving seasickness, **Lloyd Spencer Davis** ("A Superlative Penguin," page 46) traveled to the remote Antipodes Islands to observe erect-crested penguins, which nest there. Davis is used to living at the ends of the earth; he has studied Adélie penguins in Antarctica and many other penguin species, including the yellow-eyed penguins of his native New Zealand. A senior lecturer in zoology at the University of Otago in Dunedin, Davis is also the director of a program in natural history filmmaking. He is the author of *Penguin: A Season in the Life of the Adélie Penguin* (Pavilion Books, 1993) and, hot off the press, *The Plight of the Penguin* (Longacre Press, 2001).

In 1980, intrigued by W. D. Hamilton's ideas on altruism, **Bernard J. Crespi** ("Altruism in the Outback," page 56) started looking for good self-sacrificing species to study. Twelve long years later, he found what he was looking for: social thrips in the Australian outback. A native of Illinois, Crespi is a professor in the Department of Biological Sciences at Simon Fraser University in British Columbia. Besides researching thrips, he studies speciation and asexuality in walking sticks and the phylogenetics of Galápagos Islands snails and of gall-inducing social aphids. In the future, he hopes to turn his attention to sociality in organisms even smaller than thrips, such as pathogenic bacteria. Illustrator **Utako Kikutani** is a frequent contributor to *Natural History*. Her work last appeared in the April 2001 issue ("Hot Times in the Bighorn Basin" and "Wyoming's Garden of Eden").

Photographer **Jack Dykinga** ("Islands of Autumn," page 62) believes that images can spur people to protect and preserve land that is threatened by human activity. Dykinga, left, also photographs places for beauty's sake alone, as was the case with his photoessay on big-tooth maples and other flora in southeastern Arizona. A Pulitzer Prize winner, he has produced both photographs and text for several books. **Wade C. Sherbrooke** is director of the American Museum of Natural History's Southwestern Research Station near Portal, Arizona. After sixteen years of living in the Chiricahua Mountains, he says he's still learning about their moods and complexities.

Tim Flannery and **Peter Schouten**'s portfolio of text and images ("A Lost Menagerie," page 66) is drawn from *A Gap in Nature: Discovering the World's Extinct Animals*, a four-year project (published this month by Atlantic Monthly Press) documenting animal species that have disappeared within the past 500 years. Flannery, left, is director of the South Australian Museum and the author of twelve books. Schouten is a Sydney-based freelance wildlife illustrator whose many honors include the Whitley Medal, for *Tree-Kangaroos: A Curious Natural History* (1996), another collaboration with Flannery (and others).



Born in Shanghai, art historian **Jay Xu** ("The Enigmatic Art of Sanxingdui," page 72) is the Foster Foundation Curator of Chinese Art at the Seattle Art Museum. He is the organizing curator of the exhibition "Treasures From a Lost Civilization: Ancient Chinese Art From Sichuan," which is touring the United States and Canada, and a principal contributor to the exhibition catalog, *Ancient Sichuan: Treasures From a Lost Civilization,* edited by Robert Bagely (Seattle Art Museum/Princeton University Press, 2001). A future project involves China's little-known southerly silk road to India and Burma.

Photographer and filmmaker **Gary W. Griffen** ("The Natural Moment," page 92), a producer of wildlife documentaries for Discovery Channel, routinely spends three years filming animals for each of his programs. He says he'll "do almost anything for a good shot," including traveling fourteen hours to stand in -30° F weather to film bull moose shedding their antlers. Griffen's latest film, *Moose: Spirit of the North Woods*, won the Gold Camera award in the Nature and Wildlife category at the U.S. International Film and Video Festival in Chicago, and his still work has been published by *Smithsonian*, *National Wildlife*, and *National Geographic*.

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AT THE MUSEUM

Primitive *Sphecomyrma freyi* worker ants in New Jersey amber

The Perfect Fossil

To a Museum entomologist, studying a Cretaceous insect exquisitely preserved in amber is a very close second to seeing the living thing.

By Henry S. F. Cooper Jr.

Just above the Hall of Saurischian Dinosaurs on the fourth floor of the American Museum of Natural History is the laboratory of entomologist David A. Grimaldi. Entering it, one finds microscopes and computers, a battered, overstuffed sofa and easy chair, and a row of cabinets with tiers of shallow drawers. These cabinets hold 15,000 pieces of translucent, orange-yellow amber containing fossils of ancient flies, ants, and mosquitoes that would have tormented some of the dinosaurs on the floor below. Amber is greatly compressed pitch or resin from various conifers as well as from some tropical broad-leaved trees. It very likely developed early in the Cretaceous Period (135–65 million years ago) as the trees' defense against an increase in herbivorous insects. It was to the trees what flypaper is to us—much the same color and, if anything, stickier.

Grimaldi studies insect fossils in both amber and stone. The stone fossils—mostly limestone—are the more abundant and cover a broader span in space and time. Fossils in amber date from no earlier than the Cretaceous and are limited to outcrops in a few places, such as Lebanon, Russia, Myanmar (formerly Burma), the Caribbean, and the east coast of the United States, from Martha's Vineyard to Georgia.

Some twenty years ago, while a graduate student at Cornell University, Grimaldi saw his first amber fossil. It immediately grabbed his attention. "I was amazed that more entomologists weren't studying amber fossils—I still don't understand it," he says. "You can study a cell's nucleus and mitochondria under an electron microscope, even its amino acids and maybe its DNA." His fascination hasn't diminished, and in 1996 he organized the Museum ex-

hibition "Amber: Window on the Past."

Insects are descended from marine arthropods, he explains, and first appeared on land less than 400 million years ago as small, wingless bugs resembling silverfish. Between 345 and 280 million years ago, the forests buzzed with giant dragonflies. But Paleozoic insects such as these (along with 98 percent of all other life-forms) became casualties of the unprecedented mass extinction at the end of the Permian, and gradually, from the Triassic to the Cretaceous, insects evolved into more familiar forms. Says Grimaldi, "The Cretaceous interests me because that is when a lot of modern insect families evolved—and angiosperms, or flowering plants."

From his cabinets, Grimaldi produces two small bits of Cretaceous amber, one encasing a tiny bee, the other a small cluster of oak flowers. They might have come from Central Park, accidentally frozen into a clear orange popsicle. The 65-million-year-old fossilized bee has changed his thinking quite a bit: "We never knew or surmised there would be a bee from the Cretaceous. It's still the only bee we've found." This bee proves that bees had already evolved by then, but judging from their absence in the earlier fossil record, they were not yet plentiful. Flowering plants, on the other hand, were abundant: they appeared in the beginning of the Cretaceous, 135 million years ago, and explosively radiated 35 million years later, eventually becoming the dominant form of multicellular plant life on Earth.

Not only bees but also moths, butterflies, and long-tongued flies are relatively scarce in the Cretaceous fossil record, raising interesting questions: What was pollinating the flowers and causing their proliferation? What was decomposing the carcasses, given the total absence of fossils of the larger flies, such as flesh flies and blowflies (whose larvae, which we call maggots, feed on carrion)? And finally, since termite fossils are rare, what decomposed all the Cretaceous plant matter? We don't know.

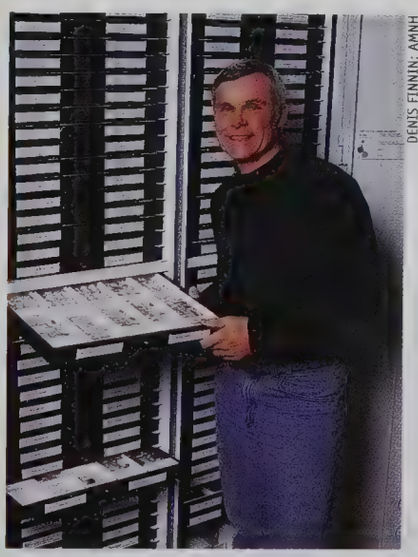
In another cabinet drawer is a 90-million-year-old ant from an amber deposit in New Jersey; this ant defended itself not by stinging but by spraying formic acid. Grimaldi believes the existence of this fossil suggests that ants may have evolved as early as 110 million years ago.

Ants, like termites, were rare and primitive in the Cretaceous, but they were already social. Some of Grimaldi's pieces of amber have several ants in them—an unlikely occurrence unless the insects spent a lot of time together. And after identifying worker ants in several of the fossils, he believes that ants had already begun to specialize into castes. In addition, many species of Cretaceous ants and termites display a variety of specialized structures, another feature of social insects.

"For years, people who have studied social insects like ants, termites, bees, and certain kinds of wasps have said that sociality was critical to a group's abundance and a driving force in its ecological success and diversity," says Grimaldi. "But apparently not, for ants just squeaked along for their first 50 million years of existence, even though they were social. For some reason, at the beginning of the Tertiary Period, around the Paleocene or the lower Eocene, they became abundant and diverse. And the studies I am doing with termites reveal the exact same thing."

If sociality wasn't responsible for social insects' success, what about the effects of the cataclysmic impact that marked the end of the Cretaceous and the beginning of the Tertiary, an interval often called the K-T boundary? After all, if the resulting cold and darkness killed off dinosaurs and allowed our own rare and primitive shrewlike ancestors to radiate, might it not have performed the same service for the ants, termites, bees, and wasps by getting rid of their competitors?

Grimaldi thinks not. The fossil record for insects just before and just after the K-T boundary is virtually nonexistent. There is evidence over the broader sweep of time, however, that these insects made it through unscathed—and that the insects that might have been their competitors did not go extinct. Grimaldi attributes the increase of social insects in the Tertiary to climate change, their own evolution, and the further evolution of flowering plants. Meanwhile, he continues to search for new amber deposits, certain they will offer a window on insects' past.



***Kyromyrma neffi*, left, the oldest formicine ant. Right: David Grimaldi in his Museum lab.**

Henry S. F. Cooper Jr., a former staff writer for the New Yorker, *has been visiting the Museum since he was four years old, when his father sat him in a cavity of the Willamette meteorite.*

MUSEUM EVENTS

NOVEMBER 2 THROUGH 10
THE 25TH ANNUAL MARGARET MEAD

FILM & VIDEO FESTIVAL

This year's program celebrates the centennial of the birth of Margaret Mead (1901–1978), the Museum anthropologist in whose honor the international film festival was established. Among the featured films are *Cannibal Tours* (1988) and *Cunnamulla* (2000), by Dennis O'Rourke; *Shinjuku Boys* (1995) and *Runaway* (2001), by Kim Longinotto; the Papua New Guinea series (1983–92) and *Facing the Music* (2001), by Bob Connolly and Robin Anderson; and *The Belovs* (1992) and *I Loved You . . . (Three Romances)* (2001), by Victor Kossakovsky. Also highlighted are selections from the Jakarta International Film Festival. Visit www.amnh.org/mead for the screening schedule and descriptions of the films.

Dennis O'Rourke's *Cannibal Tours*

NOVEMBER 5
Lecture: "Parallax: The Race to Measure the Cosmos" (Distinguished Authors in Astronomy series). Alan Hirshfeld, of the University of Massachusetts Dartmouth's observatory. 7:30 P.M., Space Theater, Hayden Planetarium.

NOVEMBER 7 AND 14
A geological tour examines the granite and marble that make up AMNH's walls and facade: "Sensing the Museum Inside/Out." Sidney S. Horenstein, coordinator of the Museum's environmental public programs. 3:30–5:00 P.M. Meet at 77th Street entrance.

NOVEMBER 14, 15, 16, AND 20
Panel discussion: "DNA and Privacy." Bioethicist Peter Singer, of Princeton University; forensic DNA researcher and attorney Elisabeth A. Palladino, of Harvard University; and Susannah Baruch, director of legal and public policy, National Partnership for Women and Families. November 14, 7:00 P.M., Kaufmann Theater. Presented in conjunction with the exhibition "The Genomic Revolution" (on view through January 1, 2002, in Gallery 3). Workshops on genetics: November 15 and 16, 9:00–11:00 A.M. and 7:00–9:00 P.M.; follow-up explanation session, November 20, 7:00 P.M.

NOVEMBER 16, 17, AND 18
Symposium: "Taino Revivalism in the 21st Century: Cultural Heritage of Caribbean Indigenous Peoples" (Identities Beyond Borders series). Moderated by Gabriel Haslip-Viera, editor of *Taino Revival: Critical Perspectives on Puerto Rican Identity and Cultural Politics.* November 17, 2:00–5:00 P.M., Kaufmann Theater. Programs are presented throughout the weekend. For information, call (212) 769-5315 or check www. amnh.org/programs.

NOVEMBER 26
Lecture: "Solar Influence" (Frontiers in Astrophysics series). Astrophysicist Sallie Baliunas. 7:30 P.M., Space Theater, Hayden Planetarium.

NOVEMBER 27
Lecture on upcoming sky events: "Celestial Highlights." Joe Rao, columnist for the *New York Times* and *Natural History;* astronomers Steven Beyer, Hank Bartol, and others. 6:30 P.M., Space Theater, Hayden Planetarium.

DURING NOVEMBER
Field trips, walking tours, and workshops for children and adults, both inside and outside the Museum. For information, call (212) 769-5200.

For news from the Center for Biodiversity and Conservation, see research.amnh.org/biodiversity/center/newsletter/webletter.html.

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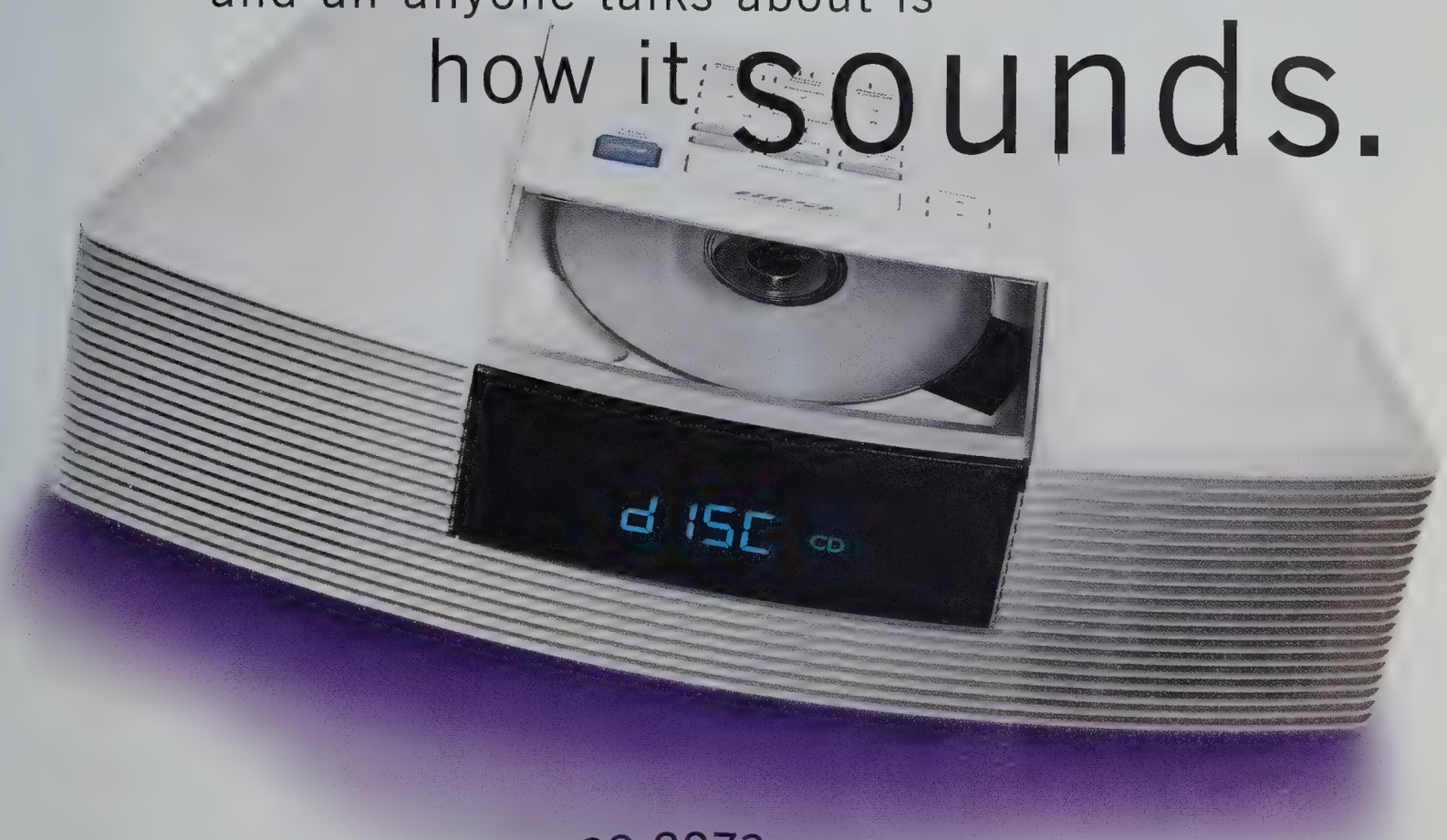

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FINDINGS

How to Stalk a Spitting Spider

On a mountain in the Philippines, the hunter risks becoming the hunted.

By Robert R. Jackson and Simon D. Pollard

Eye to eye and head to head,
This shall end when one is dead;
Turn for turn and twist for twist—
Hah! The hooded Death has missed!
—Rudyard Kipling, *The Jungle Book*

Rudyard Kipling's story of the battle between the mongoose Rikki-tikki-tavi and two cobras has a surprising parallel in the spider world. *Portia labiata,* a spider with the cunning of a mongoose, hunts and is hunted by *Scytodes pallidus,* a spider with the defenses of a spitting cobra. While Kipling set his story in an Indian bungalow and garden, our story takes place in a rainforest on the slopes of Mount Makiling, about forty miles southeast of Manila on the Philippine island of Luzon.

Having built its web in the cup of a partly folded leaf, *Scytodes* sits with its feet splayed on the strands of silk, "listening" for telltale vibrations that will signal the arrival of a possible prey or predator. It is oblivious to being watched by *Portia,* a clever jumping spider that views *Scytodes* as a potential meal. Surveying the surrounding vegetation with its keen eyes, *Portia* initiates a plan of attack that will thwart its target's formidable defenses. First it approaches the edge of the web and, using its palps (small, leglike appendages close to the mouth), softly plucks the web's silk lines. The finely tuned signal has the effect of bringing *Scytodes* into the open without provoking an attack. *Portia* then starts to climb toward a leaf directly above the web. Often losing sight of its prey, *Portia* spends twenty minutes detouring through the foliage to reach the optimal vantage point. Peering down on its intended victim, *Portia* situates itself so that it can land in a prime position to grab its prey from the rear. Then it leaps.

In an instant, the tables are turned. As *Portia* jumps, one of its legs touches a silk strand, spoiling its aim and alerting *Scytodes* to the presence of an intruder on the web. Whirling around to face the danger, *Scytodes* fires a stream of sticky glue at *Portia* from its mouthparts. The jumping spider is hopelessly trapped, pinned down by the glue. The web's resident spider delivers the coup de grâce by burying its fangs in *Portia*'s head and injecting venom. This time, the would-be diner has become dinner.

Both these species have a predilection for arachnid flesh but are otherwise quite different. Instead of constructing a web, *Portia* uses its eyes and brain to stalk and pounce. Unlike most spiders, *Portia* has eyesight that rivals our own; it is capable of seeing size, color, and shape. Web-building spiders such as *Scytodes* have much weaker eyesight and instead rely heavily on interpreting the signals from movement and variations in tension of the strands of their webs. *Portia* exploits this sensory system by manipulating the web silk in numerous and often subtle ways as it seeks to gain control over the other spider's behavior. Sometimes, perhaps expecting to catch a struggling prey insect, the duped *Scytodes* rushes into *Portia*'s waiting arms. At other times, *Portia* entices its victim out into the open to investigate and then positions itself for the kill.

While *Portia*'s advantage is its acute

ALL PHOTOGRAPHS BY ROBERT R. JACKSON

In this battle, the cunning *Portia* (top) has overcome *Scytodes,* the spitting spider.

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A female *Scytodes* carrying spiderlings on her back and an egg sac in her mouth is easy prey for a jumping spider.

eyesight, which allows it to monitor every move of its prey, *Scytodes*'s advantage is its headful of ammunition. Most spiders produce venom and all have fangs, but *Scytodes* has an additional weapon: Connected to the venom glands inside its disproportionately large head are glands that contain a sticky gum. By contracting muscles around these glands, *Scytodes* can fire a wad of venom-laced glue over distances of an inch or more within half a second, quickly paralyzing both prey and predators.

About 130 *Scytodes* species exist worldwide, and they are the only spiders that spit. *S. pallidus* is found in different parts of Asia, but as far as we know, the only ones whose standard fare is jumping spiders are those that live on and around Mount Makiling. They weave sparse, nonsticky webs on the large leaves of trees and shrubs. Jumping spiders are very common in the same habitat and often trip over *Scytodes*'s web lines, eliciting spitting attacks.

There are about 15 species of *Portia* in the world. All of them specialize in eating spiders—other jumping spiders as well as web builders. In the area of Mount Makiling, *P. labiata* is the only jumping spider that routinely gains the upper hand and overcomes *S. pallidus*. Part of its success appears to depend on its ability to stay out of the spitting spider's line of fire.

A Portia (right) in a *Scytodes* web

But *Portia* also exploits the maternal behavior of *Scytodes*. Female spitting spiders are unusual in the degree of care they give their offspring. The mother carries a cluster of developing embryos in an egg sac that she holds in her chelicerae (stout mouthparts ending in fangs). And while the juveniles of most web spiders disperse after the first molt, *Scytodes* spiderlings stay with the mother until they have molted three or more times. During this period of dependency, the mother brings prey to her babies, sharing the meal with them or allowing them to eat all of it.

Since spit comes from the fangs, a *Scytodes* mother carrying an egg sac in her mouthparts is effectively disarmed. To spit, she would have to release her hold, which she is reluctant to do. *Portia* can spot the difference between a *Scytodes* that is carrying an egg sac and one that is not. In laboratory experiments, we have found that when given a choice, a Mount Makiling *Portia* will go after an egg carrier. And even though making a detour is generally the safer way to approach a spider that spits, *Portia* tends to take a fast, direct path toward an egg-carrying *Scytodes*, seemingly because the risk is minimal. Upon killing a mother, *Portia* sets her aside and, as in a tale from Greek mythology, eats the eggs before feasting on the parent.

Natural selection has obviously favored *Portia* that tread carefully where *Scytodes* live and that exploit the vulnerability of egg-carrying females. In fact, Mount Makiling *P. labiata* reared in the lab with no experience of *Scytodes* also prefer egg carriers and approach them less cautiously, so the behavior must be innate. But not all members of this *Portia* species are equally streetwise.

About 200 miles north of Mount Makiling, in Mountain Province, *P. labiata* live in a *Scytodes*-free zone. There they hunt web-building spiders but are apparently oblivious to the special danger posed by the ones that spit. When tested in a lab, these *P. labiata* tried an array of signals on the *Scytodes* web, often provoking the intended victim to spit. They also failed to detour into positions from which they could attack *Scytodes* safely, from the rear. Instead *Portia* often tried to walk directly onto the web. It was usually a fatal mistake.

Robert R. Jackson is a professor of zoology at the University of Canterbury; Simon D. Pollard is Curator of Invertebrate Zoology at Canterbury Museum and a senior fellow at the University of Canterbury, both in Christchurch, New Zealand.

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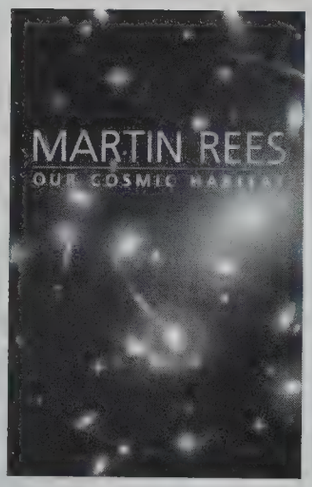

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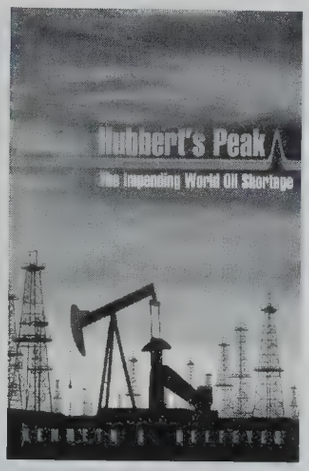

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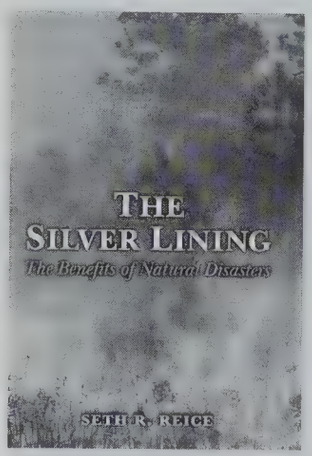

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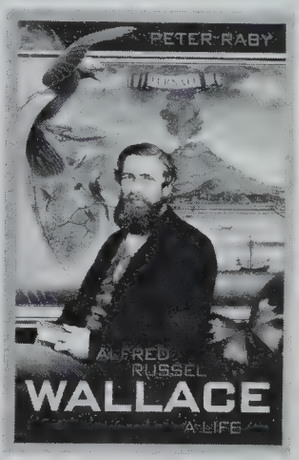

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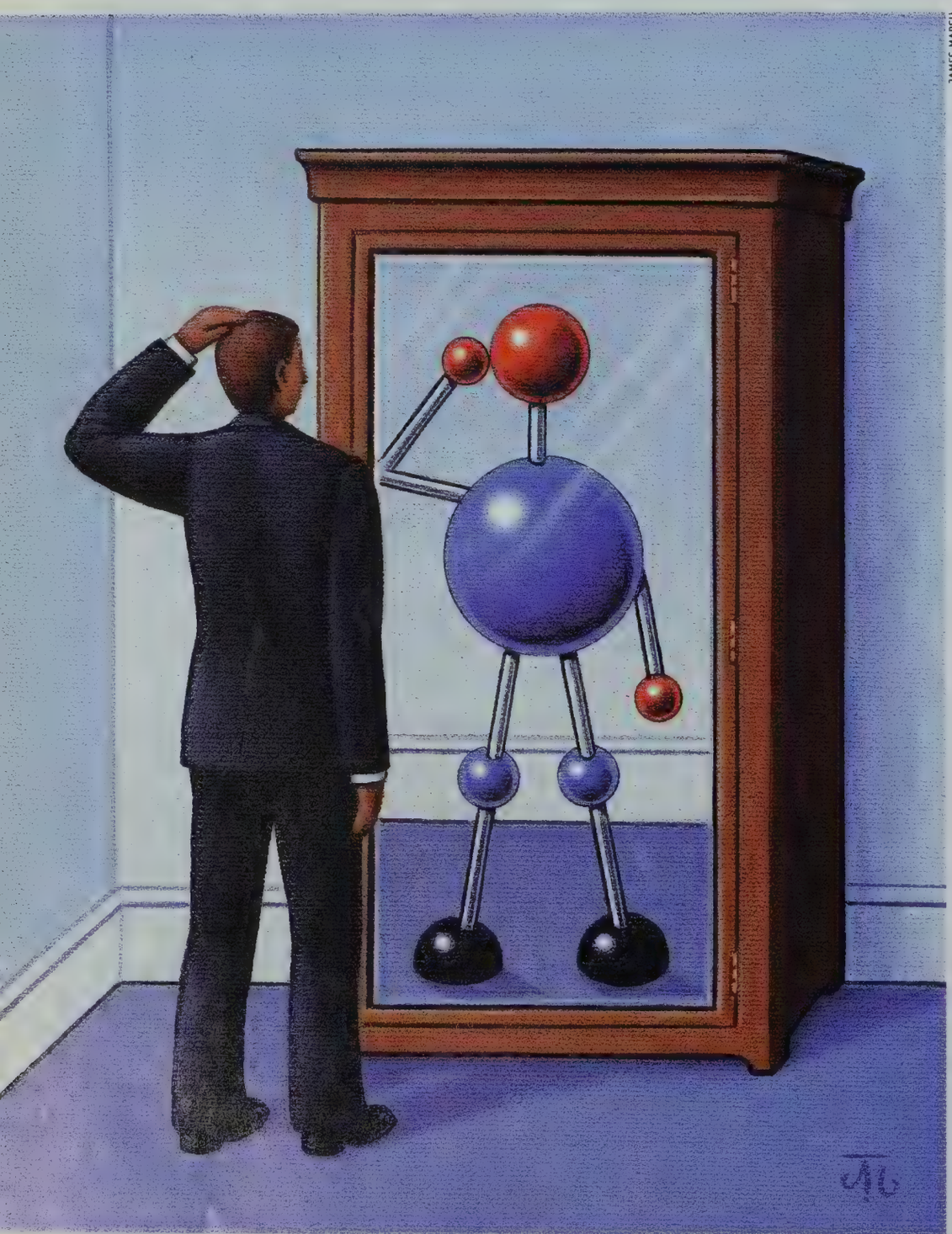
THE EVOLUTIONARY FRONT

Us and Them

Junk DNA raises the question, Whose life is it anyway?

By Carl Zimmer



JAMES MARSH

The February 15, 2001, issue of *Nature* was a peculiar one. Lodged in the middle of the journal was a kind of scientists' centerfold: a multipage foldout covered in long trains of tiny hatch marks, alphanumeric codes, and squiggly graph lines. Here, for the first time in print, was a rough draft of the human genome—what Francis Collins, head of the U.S. Human Genome Project (HGP), called "the first glimpses of our instruction book, previously known only to God."

It certainly gives one pause to look at this sprawling map and think about what it represents. It's even tempting to imagine we are peering at a biological version of the soul, the unique essence that determines us both as a species and as individuals. But be careful when you turn to your genome to search for your soul. Where you expect to find your true inner self, you will come face-to-face with a mob of strangers.

Researchers now estimate that the human genome contains roughly 40,000 genes—those stretches of DNA that make the proteins that a cell needs to survive. That's up from the figure of 30,000 published last February, but these 40,000 genes still constitute only about 2 percent of the full human genome. What's the other 98 percent? In the 1970s, when geneticists first began to look at it, they dubbed this extra material "junk DNA."

The implication of the nickname

was that there was nothing interesting or important about the stuff. It is true that a sizable portion of the DNA that isn't part of a gene fits this definition. Known as "pseudogenes," these segments of DNA are the mutated relics of genes that once encoded proteins. But a large portion of the junk DNA—amounting to about 40 percent of the human genome, in fact, according to an HGP estimate—actually has a life of its own.

An ordinary gene can duplicate itself only when a cell divides and makes a new copy of the entire genome. Certain kinds of junk DNA don't have to wait that long. Instead they may, for example, harness the cell to copy them in the form of a segment of RNA, the single-stranded version of the genetic code. Normally, RNA is used by the cell during the production of proteins. But in the case of some junk DNA, the cell uses this RNA to create another DNA copy of the junk segment, which it then inserts somewhere else in the genome. Researchers call such self-replicating pieces of junk DNA "transposable elements" because of the way they transpose copies of themselves into new places in the genome.

Why do some species have lean, mean genomes with hardly any junk, while others are overwhelmed by it?

The more researchers have studied transposable elements, the more these bits of DNA have come to seem like a collection of parasites that use the genome as their host. We tend to think of parasites as autonomous organisms—hookworms or lice, for instance—not as our "own" genetic material. But during the 1980s and 1990s, the metaphor of genetic parasites turned out to be very powerful. Parasites tend to follow certain evolutionary paths, and these genetic parasites are no exception.

Like other parasites, transposable elements can cause a lot of harm to their host—such as by pasting a copy of themselves smack in the middle of a gene. When it comes time for the cell to build a protein based on that gene, it may be unable to do so because the inserted DNA has turned the gene's code to gibberish. Researchers are discovering more and more forms of human genetic disorders—ranging from hemophilia to breast cancer—that have come about because a transposable element has hopped into an unfortunate place in the genome.

Another hallmark of parasites is that hosts often evolve defenses against them. Transposable elements appear to be no exception to this rule. In certain regions of our genome, for example, our DNA is capped with hydrocarbon molecules. This capping (called methylation) prevents the cell's DNA-copying machinery from locking onto the genetic material in those parts of the chromosomes. Researchers suspect that in many cases, methylation is the genome's way of fighting against the damage caused by transposable elements—by stopping them from reproducing.

In the May 10, 2001, issue of *Nature,* for instance, a group of Japanese researchers described their study of methylation in the genome of the thale cress plant *(Arabidopsis thaliana).* They found that if a certain gene mutated, the plant could no longer methylate its DNA. Freed from their prisons, the transposable elements in these mutants started replicating themselves and inserting these new copies into the genome. The resultant plants were nothing more than shriveled clumps. Thanks only to methylation, it seems, can the thale cress withstand its genetic parasites.

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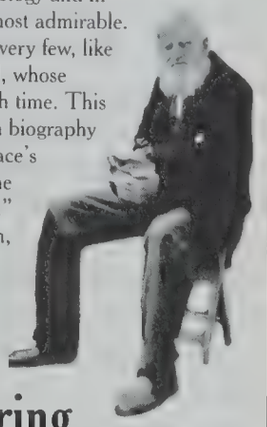

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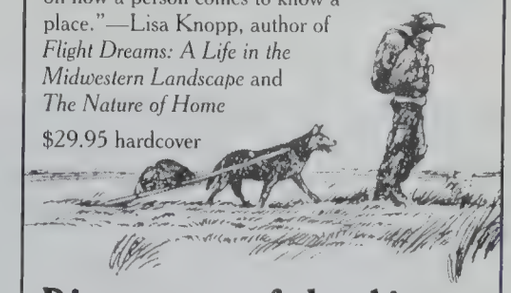

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This discovery points up a conundrum that arises as much in connection with transposable elements as with conventional parasites: if they can be so harmful to their hosts, why haven't they driven their hosts extinct—and made themselves extinct in the process? Part of the answer comes from their evolutionary history. Transposable elements can spread gradually through a genome over millions of years, but eventually their success at self-replication wanes. Copying errors creep in and undermine their ability to replicate themselves; in addition, the host genome evolves an ability to suppress them. Most of the transposable elements in the human genome, it now seems, are already dead or about to give up the ghost.

Your genome is an ancient ecosystem in which hundreds of thousands of mysterious life-forms compete, cooperate, co-opt one another, and coevolve.

The only way a transposable element can escape this fate is to leave its host and find a fresh genome to invade. By comparing transposable elements found in an array of hosts, researchers have discovered that these genetic parasites can make astonishing leaps—from marine flatworms to beetles, for example, or from salmon to frogs—although no one knows for sure how they manage these migrations. Perhaps certain mutations turn the transposable elements into full-fledged viruses—nucleic acid molecules covered in protective protein shells. They can then exit their host, find a new one, and snuggle into its genome. Some of today's transposable elements might have once been free-ranging viruses, and some contemporary viruses may have had transposable elements as ancestors.

Through migration and proliferation, transposable elements have become inordinately successful, and that is how they have come to constitute 40 percent of our DNA, either as active copies or dead ones. Much of the remaining junk DNA in our genome may also turn out to be former transposable elements that have mutated beyond recognition. In certain species the proportions are even more staggering: 99 percent of the lily genome consists of transposable elements.

Despite what we know about transposable elements, can't we still salvage the notion of the genome as the biological soul? When I look at the map of the human genome, don't I still see "myself" in the genes that code for useful proteins—albeit a self that is besieged on all sides by these annoying parasites? The answer, it increasingly seems, is no. You can't draw a line in the genome between us and them.

One of the best places to see this fuzziness is in the arid canyons of Israel. The wild barley plants that grow there carry many copies of one family of transposable elements, called BARE-1. Alan Schulman, of the University of Helsinki, and his colleagues recently studied a single population of barley plants in one of these canyons. They found that the plants growing at the top of the canyon carried three times more BARE-1 copies than did the plants of the same species growing at the bottom, where conditions are less harsh. Similar patterns have emerged throughout Israel and surrounding countries. In other words, having a lot of BARE-1 copies somehow seems to allow barley to survive under arid conditions.

One possible explanation is that transposable elements make the genome physically big, which is sometimes a good thing. In 1978 Thomas Cavalier-Smith, then at the University of British Columbia, proposed that the sheer size of a genome can sometimes be an adaptation. Since then, this idea has been generating much controversy as it floats around the scientific community. Its main attraction is that it addresses a fundamental puzzle about DNA: Why do some species have lean, mean genomes with hardly any junk, while others are overwhelmed by it?

A species with a sizable genome may simply have had the bad luck to be attacked by a particularly nasty transposable element. But it's also possible that genomes of certain sizes may be favored under certain circumstances. Big genomes tend to be found in big, slow-dividing cells. As genomes expand, the cells they inhabit may have to expand with them to accommodate a larger crew of proteins employed in keeping the genome in good working order. Getting these bigger cells to divide may also be a bigger undertaking, and this would make them multiply more slowly.

Large, slow-dividing cells may outperform small, quick-dividing ones in some situations. If a plant can grow to a good size, it can capture more sunlight and make more seeds. But plants also need water to grow, and in Israel and the rest of the eastern Mediterranean region, winter is when the most water is available. Since the relatively cold temperatures slow down the chemical reactions involved in cell division, plants may grow by developing fewer, bigger cells instead of a lot of small ones. In the case of the barley plants, the climate at the top of the canyon is much harsher than the climate at the bottom, favoring bigger genomes and the bigger cells they bring. It's possible that similar tradeoffs have driven the evolution of different-sized genomes not just among plants but maybe among animals, fungi, and amoebas as well. So while

transposable elements may indeed be genetic parasites, they may end up helping their hosts.

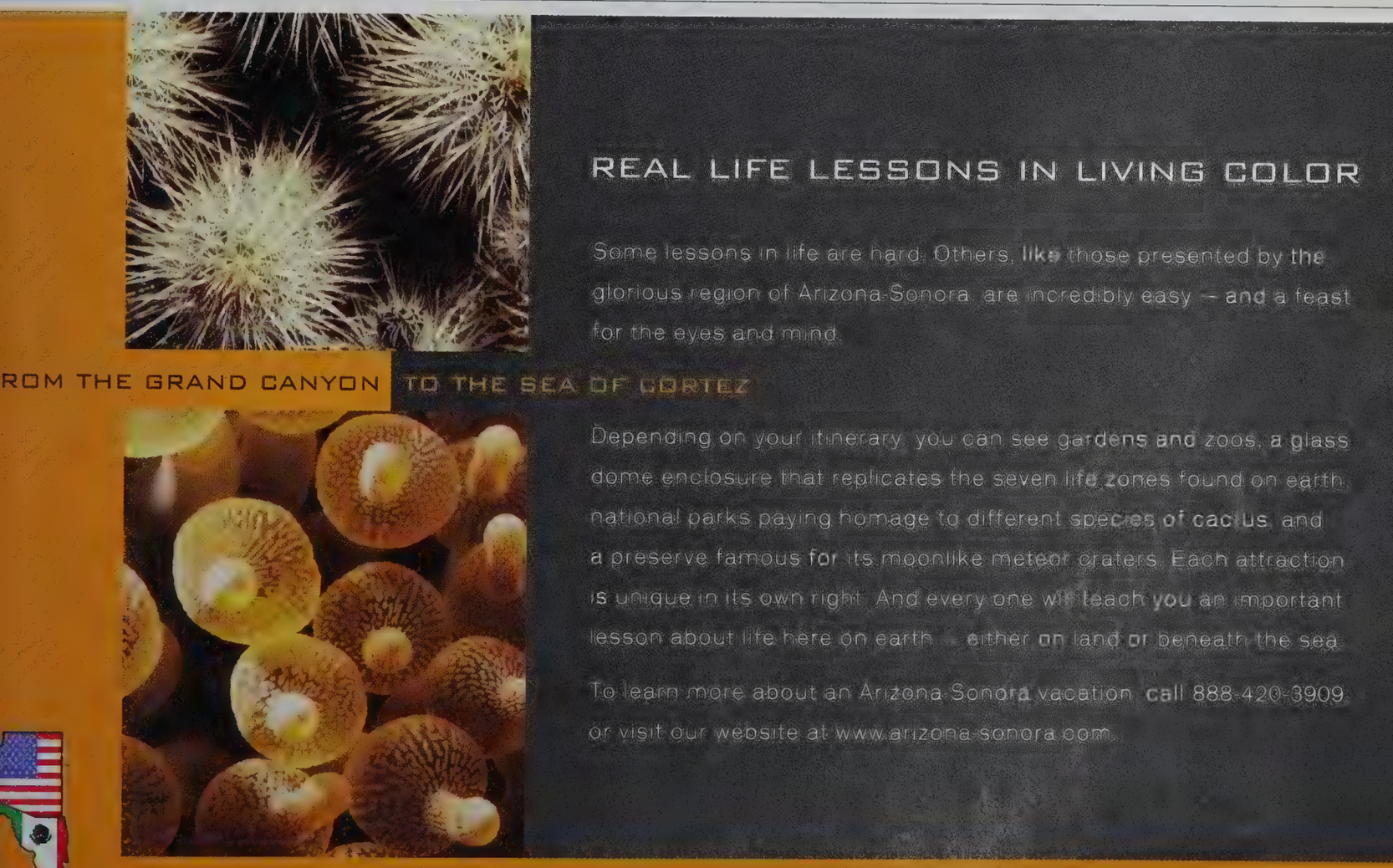
Transposable elements also appear to play a crucial role in the evolution of the cell's "legitimate" genes. Genes can evolve only if they first mutate, and transposable elements create a significant fraction of a genome's mutations. Like other kinds of mutations, most of those caused by transposable elements are neutral or harmful, but some of them can do an organism good. Sometimes, for instance, these mobile genetic parasites drag a piece of a neighboring gene with them to their new home. In the process, they link two preexisting chunks of genes into a new combination that may quickly take on a new function.

Transposable elements themselves have even become vital parts of genes. About 500 million years ago, for example, a transposable element in the genome of early vertebrates was incorporated into a gene that became part of our immune system. This ex-parasite stopped using its DNA-splicing skills to replicate itself and instead began rearranging the genes that encode pathogen-recognizing proteins. Thanks to this transposable element, our immune cells can quickly generate millions of different-shaped proteins. Through a process much like natural selection, the cells with proteins that allow them to identify pathogens will survive and can then be made to alter their genes again to do an even better job. In other words, it is only thanks to an erstwhile parasite that we can fight off other parasites.

This example of an adopted transposable element is just one of hundreds that geneticists have uncovered, and the list keeps growing. These discoveries have left biologists groping for new kinds of metaphors to describe the genome. In a review article concerning transposable elements, published in the January 2001 issue of *Evolution,* biologists Margaret G. Kidwell and Damon R. Lisch sounded downright Zen. "Who are we and who are they, who is host, and who is parasite can be seen as a function of how selection is operating at any given time," they wrote, adding that in specific cases "these distinctions can become meaningless."

I highly recommend mulling over riddles like that one while you gaze at the map of the human genome. The self can be found everywhere and nowhere on that chart. Your genome is an ancient ecosystem, a jungle, a tangled bank of a river, in which hundreds of thousands of mysterious life-forms compete, cooperate, co-opt one another, and coevolve. In the words of the immortal Pogo, "We have met the enemy and he is us."

Science writer Carl Zimmer is the author of Evolution: The Triumph of an Idea *(HarperCollins, 2001). His book* Parasite Rex: Inside the Bizarre World of Nature's Most Dangerous Creatures *has just been published in paperback.*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IN THE FIELD

A Turtle Out of Water

To freeze or not to freeze: a hatchling's dilemma

By Peter J. Marchand

ZIG LESZCZYNSKI; ANIMALS ANIMALS

Like the hatchlings of many other turtle species, this eastern painted turtle emerges into a cold world.

It was a sobering sight, one of those encounters that awakens you to the harsher realities of nature. The ground was dug up and strewn with white, leathery shells—remnants of about ten eggs, near as I could tell. From the tracks in the loose soil, I guessed that a skunk had discovered the buried trove about forty yards from the edge of a pond and, in a single feeding spree, had wiped out a snapping turtle's reproductive effort for the year. In a poignant way, this exemplified the perilous trial of aquatic turtles out of water. Superbly adapted to adult life in the pond, they are less well equipped for their start on land. And hungry predators aren't the only obstacle between turtles and the safety of water; many hatchlings in northern climes, emerging in the fall, are faced with the daunting task of surviving their first winter below ground, often exposed to freezing temperatures.

Had the snapping turtle's eggs escaped predation, the young would have moved to the pond as soon as they emerged from their nest in autumn. But hatchlings of many other turtle species remain at or close to their natal site during their first winter, digging themselves out the following spring and only then migrating to water. Some, such as the yellow mud turtle, burrow deeper into the soil shortly after hatching, finding safety below the frost line. In contrast, the ornate box turtle and northern populations of the painted turtle frequently overwinter in shallower soils and, when unable to avoid freezing, show a remarkable tolerance for the formation of ice in their body tissues.

Subjected to slow cooling, hatchling turtles may begin to freeze at a temperature slightly below 27°F, with ice first forming on the outer skin and then advancing slowly toward

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the body's core, eventually cutting off peripheral blood circulation. At 25°F, slightly more than half the water in the turtle's body may be frozen, and all vital signs cease. If the temperature drops no further, the hatchlings will recover completely upon thawing.

Remarkable as this freezing tolerance is, 25°F is close to the turtle's limit of survival in the frozen state; in order to withstand lower temperatures in nature, turtles must utilize another tactic. Through a process known as supercooling, they become chilled well below the normal freezing point of their blood plasma without undergoing ice formation. As long as the water in the turtle's body tissues remains liquid, no immediate harm comes of supercooling (the presence of ice in living tissues, rather than low temperature per se, is the primary cause of cell damage). But life is tenuous in this state, for if a supercooled animal is disturbed in any way, ice may form instantaneously, spreading rapidly throughout the body and resulting in a quick death. And disturbance isn't the only risk. The presence of any impurity in the bloodstream or gut of the animal can also "seed" ice by providing a nucleus or particle around which crystals can form more easily than they can in a pure liquid. Ice in the immediate environment of the animal is a danger, too, for nothing seeds ice crystals as readily as ice itself.

The surest way for a turtle to minimize the chances of flash freezing in the supercooled state is to avoid conditions that might serve to stimulate ice formation in body tissues. Hibernating in a dry place and evacuating the gut, so that neither external ice nor intestinal impurities pose a threat, are two possibilities. While the former is partly a matter of chance, painted turtles, it appears, do systematically empty their guts of soil particles and pieces of eggshell that are accidentally ingested during the hatching process and that might provide a nucleus for ice formation. Through this evacuation alone, hatchlings can greatly enhance their supercooling capacity. Northern populations of painted turtles are ultimately able to resist freezing to temperatures as low as -10°F.

G. CARLETON RAY; PHOTO RESEARCHERS, INC.

Ornate box turtle, newly hatched

Turtle hatchlings were once thought capable of producing ice-promoting, or ice-nucleating, proteins that facilitate harmless ice crystallization at temperatures slightly below 32°F. Hatchlings could thereby avoid the risks inherent in supercooling—a benefit if their winter surroundings remain above 25°F or so. But while ice-promoting substances are often present in blood samples taken from turtles, they apparently are contaminants and are not produced by the animal. Hatchlings raised in the laboratory, free of ice-nucleating particles, can supercool to much lower temperatures than turtles raised on natural soils. Sugars and alcohols like those that protect insects in winter may likewise be naturally induced in turtles in small quantities during freezing but do not seem to be produced and stored ahead of time in the animals' bodies. While turtle hatchlings in the wild may utilize either supercooling or freeze tolerance to get through winter, whichever strategy is employed seems to be a matter of environmental circumstances. If the hatchlings ingest bits of eggshell or bury themselves in soil containing ice crystals, they will freeze at relatively high temperatures and survive only if subsequent temperatures do not go too low. In the absence of ice nucleators, they will supercool to lower temperatures and, unless somehow disturbed, survive colder winters.

One misty evening, a couple of weeks after discovering the exhumed snapping turtle eggs, I happened upon two box turtles digging nest cavities at the side of a dirt road. A short while later I encountered a skunk working its way through the tall grass at the road's edge. Between predators and the prospect of freezing, it seemed to me that a turtle out of water stood on shaky ground, and I wondered why the young of all aquatic species don't bolt for the safety of the pond as soon as they are out of the shell, rather than digging in and overwintering on land. There is no clear answer to this puzzle. While natural selection has favored certain adaptive themes for all turtles, each species has evolved a balance of traits that best suits its overall needs. And in that balance hangs the fate of many hatchling turtles, suspended for months in the uncertain limbo of the supercooled state.

Peter J. Marchand is a research ecologist at the Catamount Institute on the north slope of Pike's Peak in Woodland Park, Colorado.

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As a winter chill enters the air in the north, an estimated 250 million monarch butterflies begin their annual journey south to Michoacan, Mexico. If you're planning a trip to Mexico this winter, don't miss this amazing feat of nature and beauty, a phenomenon that not even scientists entirely understand. Leaving Canada and the United States in late October or early November, the monarchs fly approximately 70 miles per day.

When you visit Mexico to see the monarchs, take some time to enjoy the unique architecture or join the national celebration of the Days of the Dead.

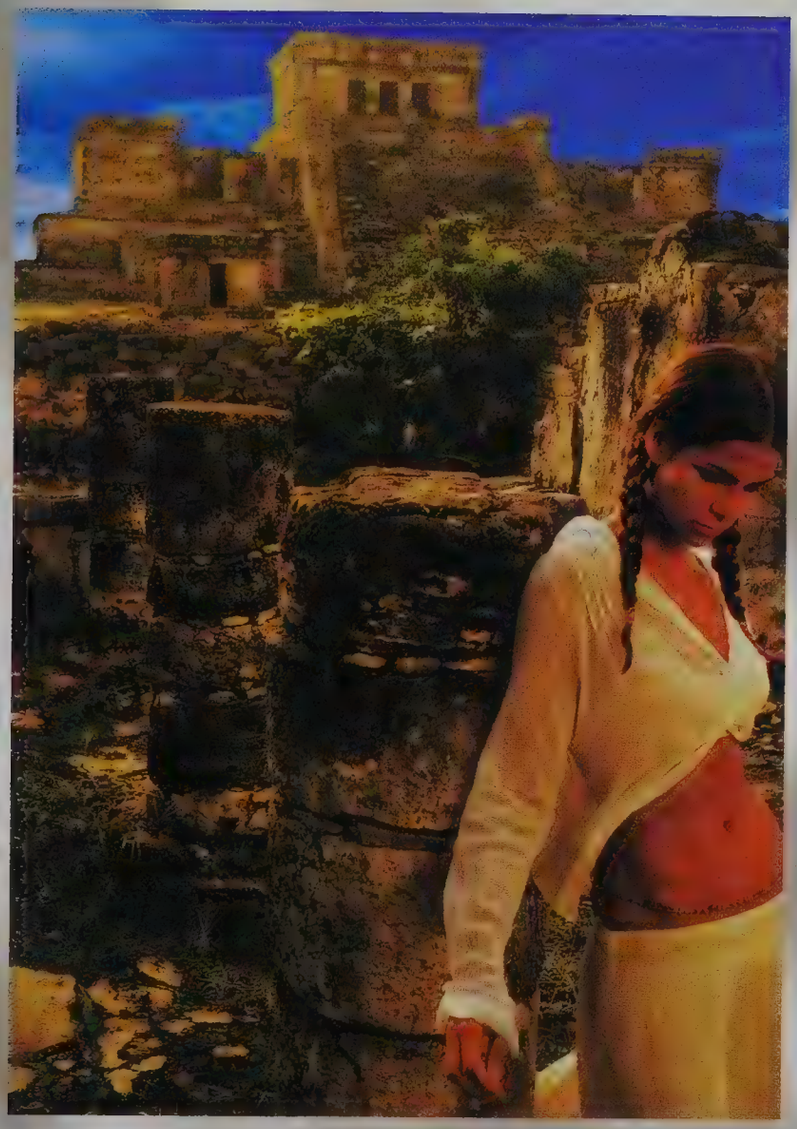
DURING THEIR MIGRATION, the butterflies fly only during the day and feed at night. Adding to the intrigue of the monarch migration is the fact that no butterfly completes the entire round-trip migration, as its life span is only a few months. The butterflies in Michoacan are the offspring of the ones that left the previous spring.

The butterflies' final destination lies in the eastern mountains of Mexico surrounding Morelia, a charming colonial city at the center of several unique tourist destinations including Lake Patzcuaro, Janitzio, and Tzintzuntzan. Here, in the Oyamel fir forests, the monarchs spend their winter waiting for the spring by hibernating, forming massive colonies in the tall pines and firs. In a semi-dormant state they conserve energy over the winter for mating. The sight of so many butterflies is overwhelming in its splendor, with the trees transformed into a bright orange carpet.

Two butterfly reserves are open to the public. The largest one, Santuario de Mariposas El Rosario, or El Rosario Monarch Butterfly Sanctuary, is located in the mountains of the Monarch Butterfly Biosphere Reserve, three hours west of Mexico City. Here, the monarchs cluster together in the pine trees, often weighing down branches with their sheer mass.

Another reserve open to the public is the Sierra Chincua Monarch Butterfly Sanctuary, which is a short distance from the small mountain town of Angangueo. Sierra Chincua offers guided horseback riding tours, as trails tend to be a little rough. Angangueo and nearby towns such as Ocampo, Zitacuaro, and Maravatio celebrate the monarch butterfly in February during the Festival de la Mariposa Monarca, which is characterized by typical dances, music, and craft markets.

I was born thousands of years ago, and soon I taught the world to count the days by the sun, the months by the moon, and the years by the stars. **Today I am affectionately called México, and I am full of intrigue and wonder.**



I am ancient.

I am outwardly beautiful and quite cultured, yet part of my being remains a mystery. I am remarkably versed in the arts, and I have many stories to tell.

Discover the many moods of MEXICO

I have many states of mind. My adventurous side leads to lush rain forests. Spectacular beaches beckon my playful attitude, with crystalline waters that are clearly invigorating. I am also sophisticated, appointed with breathtaking architecture, extraordinary works of art, and hundreds of museums filled with exquisite treasures. I will entice you with tantalizing cuisine, and when excitement stirs, my nights dance until dawn. *I am Mexico.*

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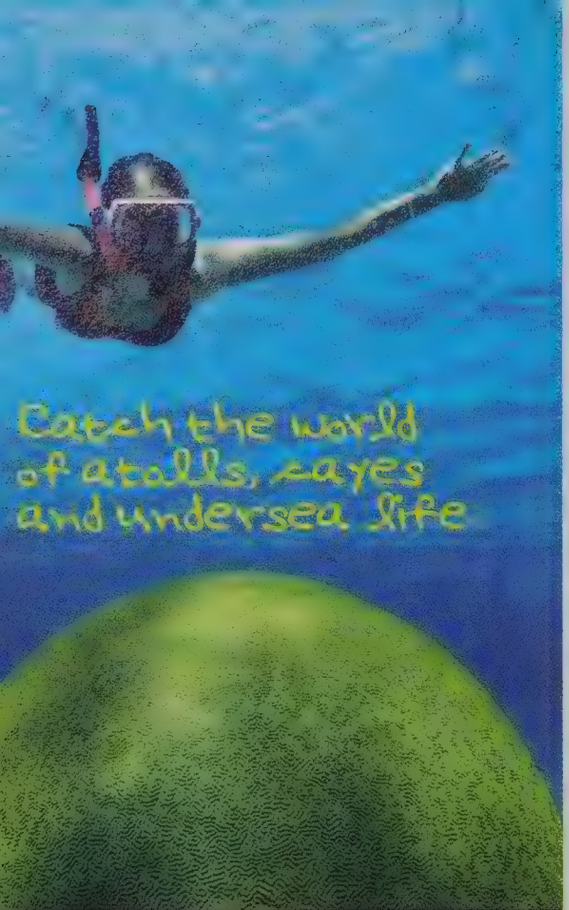

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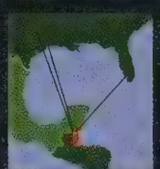

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Belize

FROM COROZAL IN THE NORTH TO TOLEDO IN THE SOUTH, Belize is known for its archaeological heritage and natural history, making it a favorite destination for many travelers. The country's significant marine environment includes the world's second longest barrier reef, as well as three major offshore atolls along the coastline. Visitors can visit numerous mangroves both offshore and along the coast. These ecosystems provide a tremendous wetlands environment in which birds, fishes, mammals, and reptiles all flourish.

Belize is also blessed with an outstanding archaeological heritage of Maya temples and palaces. The Maya occupation began as early as 1500 BC, and although it began its decline in AD 900, some Maya cultural centers continued to be occupied until contact with the Spaniards in the 1500s. Although large Maya cultural centers no longer exist, there is still a substantial Maya population residing within many small villages.

Arizona

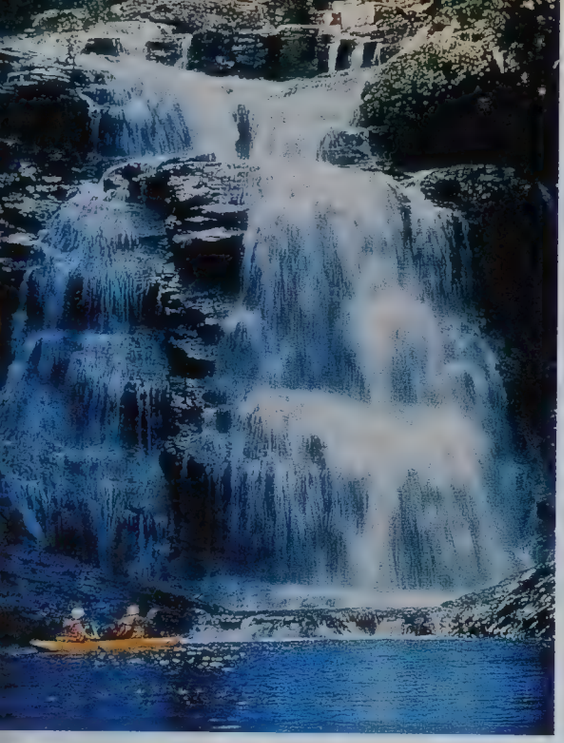
CLOSER TO HOME, Arizona offers some of the world's most awe-inspiring natural beauty. The cactus-dotted deserts, the cool pine forests surrounding Flagstaff, the red rocks of Sedona, the cosmopolitan sprawl of Phoenix, and the magnificence of Monument Valley are all part of the Arizona vacation experience.

Begin your trip in Arizona's northwest and north-central regions, home of the Grand Canyon, Sedona/Oak Creek Canyon, and the mountain community of Flagstaff. Each season brings a different palette of colors to Canyon Country and a new slate of vacation activities, from hiking and rafting to skiing and sledding.

For a taste of the culture of the Navajo and Hopi nations, visit northeastern Arizona, where you can experience the fascinating civilization and ceremonial artifacts of these Native Americans. In addition to being part of the famous point (Four Corners) where Arizona, Utah, Colorado, and New Mexico share a common border, the region is characterized by sweeping plateaus, towering mesas, and scenic canyons, and it is home to well-known attractions such as Monument Valley, Canyon de Chelly, the Petrified Forest, the Painted Desert, and Lake Powell.

The lofty mountain peaks, trout-filled streams, and thick ponderosa pine forests that distinguish the east-central Arizona region pleasantly surprise many first-time visitors to the state. Between November and March, the region is transformed into a winter wonderland for snow sports enthusiasts.

The traditional West comes alive in southern Arizona's Old West Country. From the cosmopolitan city of Tucson, home to stylish resorts and lively Western guest ranches, to the enchanting mining towns of Bisbee and Tombstone, this region is a perfect getaway from the everyday. Authentic nineteenth-century missions, country vineyards, bird-watching habitats, hiking, and colorful festivals are all part of the Old West vacation experience.



Although Belize is a relatively small country, with very low-lying land, it receives an abundance of rain during the winter season and supports 20 major river systems and smaller streams.

Arizona's Navajo Nation is home to the famed Antelope Canyon, carved from sand stone and renowned for its steep, rainbow-hued walls. If you're a photographer, a trip to Antelope Canyon is a must.

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ARIZONA
GRAND CANYON STATE

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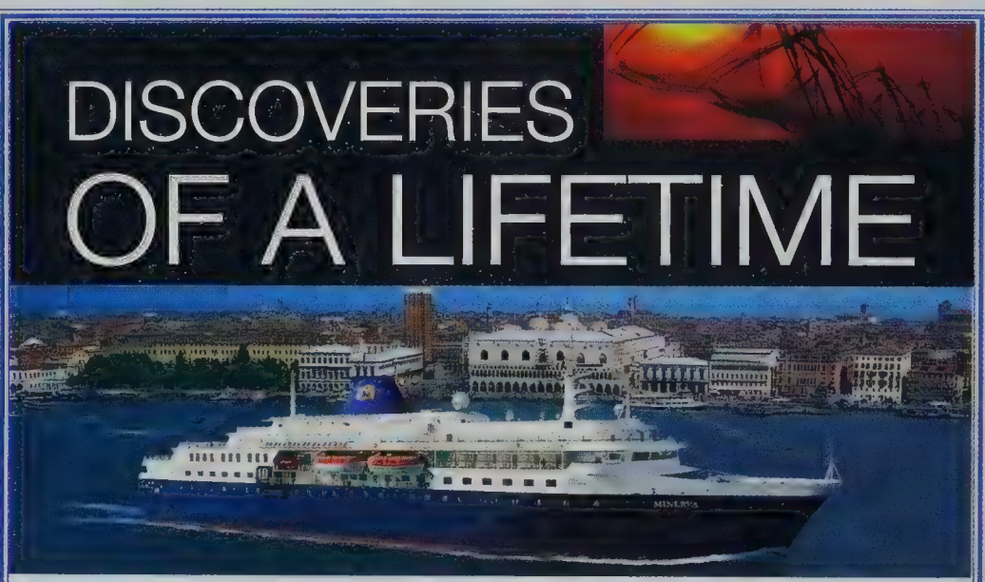

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Norwegian Tourist Board

Norway's unique an d dramatic fjords, carved by glacial ice millions of years ago, wind their way from the coast to the inland areas of Norway. Many small towns lie along the fjords, a reminder that in days gone by, waterways were always a natural traffic thoroughfare.

Set foot in the fjords of Norway and you'll know at once that every moment of your visit will be memorable.

WHEN MOST PEOPLE THINK OF NORWAY, they usually think of Norway's most spectacular natural asset, the fjords. Formed millions of years ago, these craggy coastal inlets leave visitors awe-struck with their serene beauty. One after another, they cut into the country for miles, surrounded by mountains, glaciers, and waterfalls.

Begin your Norwegian journey in the charming coastal city of Bergen. Known as the Gateway to the Fjords, Bergen is a lively city with Old World charm and atmosphere. Its wooden houses, narrow alleyways, and busy harbor give it a unique atmosphere. Take the Funicular Railway to the top of Mount Floyen, or the cable car up Mount Ulriken, for one of the most spectacular sights in Norway – Bergen framed by the sea and fjords against a backdrop of mountains. Wander around the shops of historic Bryggen, a wharf that is now an UNESCO World Heritage site.

You'll get the best view of the fjords traveling by boat or ferry. Take a fjord cruise down the Lysefjord, Hardangerfjord, Sognefjord, Geirangerfjord, or one of the many other fjords. There are daily departures from many of the towns and villages in the region, and Bergen is an ideal base from which to explore. Many tourist offices in Bergen and around Fjord Norway will book accommodations and transportation and sell tickets for sightseeing tours and other activities.

Norway

Whether it's the pristine beauty and tranquility of our fjords, the vivid reminders of our Viking heritage, or the warmth of our native Sami people, there's not a more enchanting place for a vacation than Norway. Call **1-866-6-NORWAY** (866-666-7929) for more information, or visit **www.visitnorway.com/us**.

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Norway Norwegian Tourist Board

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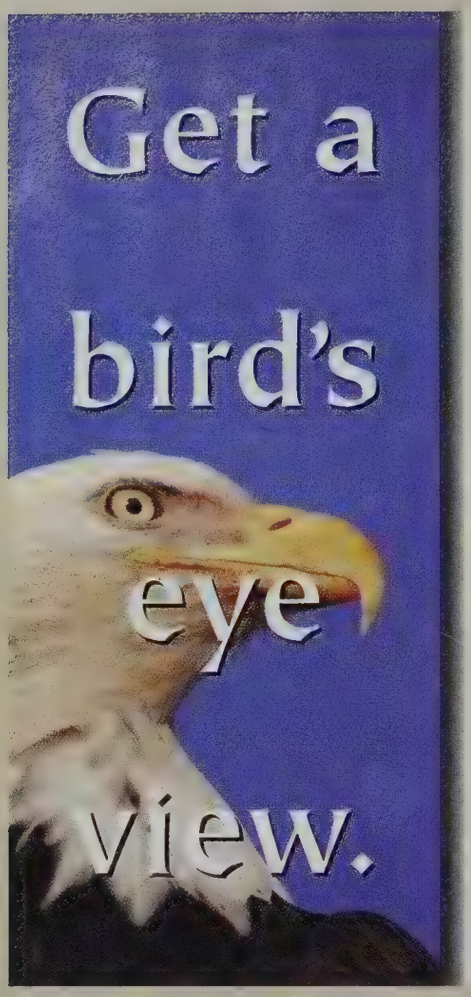

View America's symbol –*the bald eagle*– in its natural habitat, the Pocono Mountains. Along the Upper Delaware River, Pike and Wayne counties host the largest population of bald eagles in the northeast. For your **FREE** Vacation Guide or for immediate reservations, visit **800poconos.com**.

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Poconos

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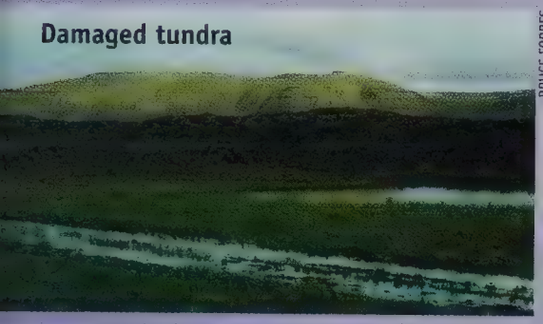
IN SUM

Don't Tread On It The Arctic's delicate tundra plants support large populations of animals such as caribou and provide nesting habitat for huge numbers of birds. The Bush administration's plan for oil drilling in the Alaskan



Damaged tundra

BRUCE FORBES

wilderness, plus the advent of global warming, has environmentalists worried about the tundra ecosystem. New research shows that minor alterations caused by human intrusions into both the High and the Low Arctic landscapes may be just as detrimental as the more apparent, larger-scale menaces. Bruce C. Forbes, of the Arctic Centre at the University of Lapland in Finland, and colleagues recently summarized the results of numerous studies examining small-scale threats to the tundra of Alaska, Canada, Greenland, and Siberia.

The researchers compared the plant communities in undisturbed patches with those in patches that had previously suffered damage from humans but had subsequently been on the mend for several decades. They found that only the smallest, wettest patches of tundra recovered on their own from extreme injury—the sort that removes all aboveground plant matter. But even patches that retained an intact plant layer were often permanently altered.

Some of the most severe damage was caused by trucks, vans, and other heavy vehicles. Just one pass of such a vehicle during the summer months left ruts that drained the water from wetlands. The explosive growth of ecotourism has also wounded the habitat; hiking, for example, has compacted soils and destroyed vegetation. Willows, horsetails, and certain grasses have readily regenerated in these trampled areas, taking over where a formerly diverse plant community once flourished. The researchers warn that a series of seemingly insignificant disturbances will nibble away at species diversity, changing the sensitive landscape forever. ("Anthropogenic Disturbance and Patch Dynamics in Circumpolar Arctic Ecosystems," *Conservation Biology* 15:4, 2001)—*Kirsten L. Weir*

Nature's Candy Flowering plants have evolved many clever ways to get themselves pollinated; one of the best is to compensate pollinators with tasty treats. Among plants pollinated by birds, such rewards usually are given in the form of liquid nectar. Now Marlies Sazima, of the Universidade Estadual de Campinas in Brazil, and colleagues have discovered a novel plant prize: candy pellets.

Jelly-laden *Combretum lanceolatum*

MARLIES AND IVAN SAZIMA

The researchers studied *Combretum lanceolatum,* a shrub that grows along muddy riverbanks and ponds in western Brazil's Pantanal floodplain. They found that each of the shrub's flowers produces a single clear jellylike pellet, formed when the plant's inner wall swells and gelatinizes as it comes in contact with nectar. Oozing out of the flower's center, this mixture solidifies into a sweet gumdrop. Unlike liquid nectar, these floral confections aren't renewed after they've been eaten.

Over a total of eighty-seven hours, team members recorded twenty-eight species of birds, from eight families—most often parakeets, macaws, kiskadees, tanagers, and finches—dining on the sweets. Perched on the shrubs to collect the pellets, the birds often brushed against the showy greenish flowers, dusting their throats and breasts with pollen. Thanks to this reproduction strategy, the plant is spreading rapidly. ("The Sweet Jelly of *Combretum lanceolatum* Flowers [Combretaceae]: A Cornucopia Resource for Bird Pollinators in the Pantanal, Western Brazil," *Plant Systematics and Evolution* 227, 2001)—*Kirsten L. Weir*

Mutant Ninja Bacteria Drug-resistant bacteria—a worldwide problem resulting from the indiscriminate use of antibiotics—are particularly threatening in developing countries. Overuse of antibiotics has been shown to drive the evolution of mutant strains of bacteria immune to a broad spectrum of drugs, including penicillins, cephalosporins, and quinolones. Now scientists have found that these multiple-drug-resistant, or MDR, bacteria can find their way from an infected hospital patient's digestive system into hospital effluent and thence into community sewage systems.

V. Chitnis, of Choithram Hospital and Research Centre in Indore, India, and colleagues compared the bacterial concentration in the runoff from ten hospitals with that in sewage from eleven residential areas. They found that although effluent in Indore's residential areas had a higher overall bacterial count (which the team attributes to a lower concentration of disinfectants and antibiotics than is found in hospital runoff), the proportion of MDR bacteria in hospital samples was significantly higher. What's more, higher concentrations of resistant bacteria were detected, in some cases, more than a mile from the point where the hospital effluent had entered the municipal sewage system.

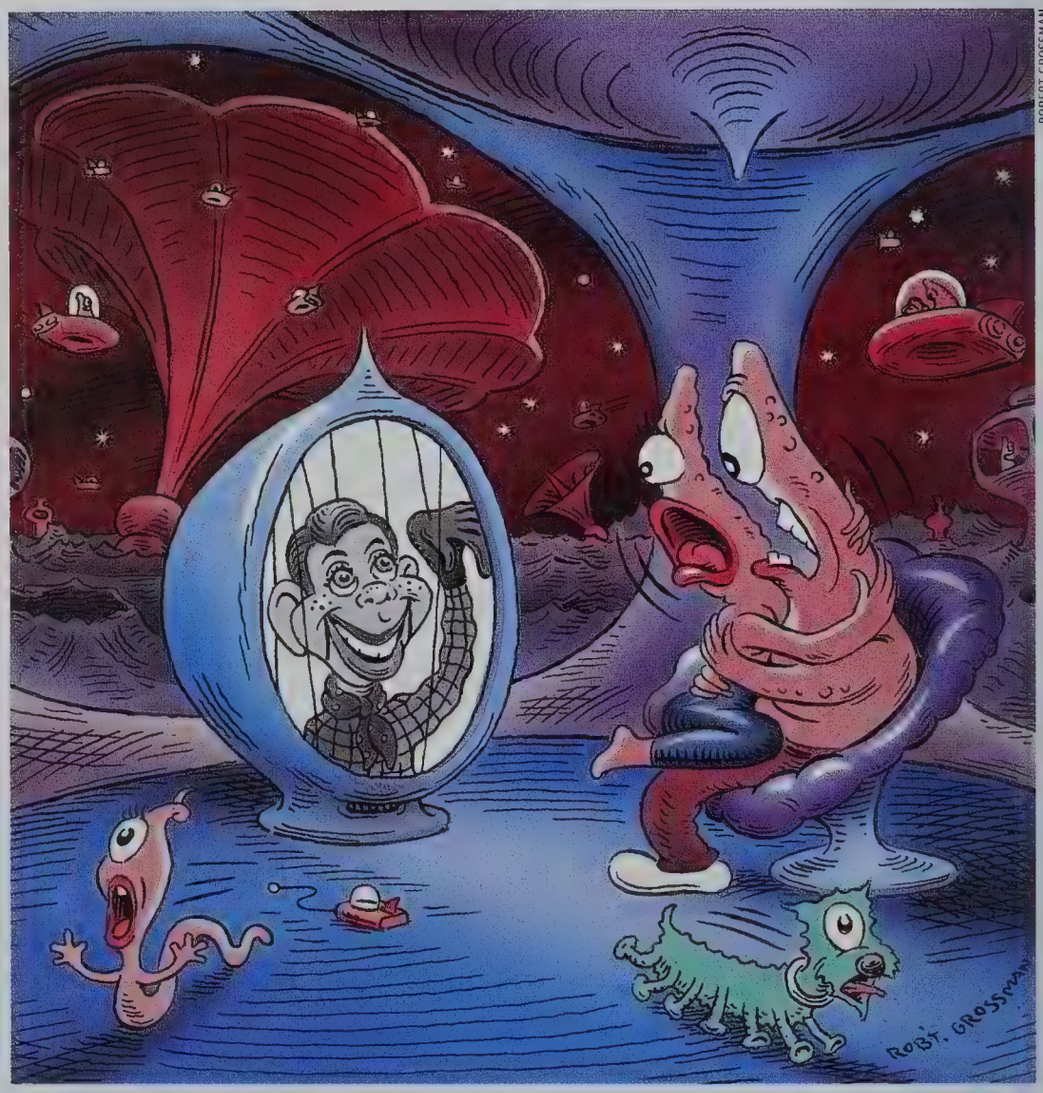
These MDR bacteria are able to proliferate because resistance plasmids—genetic elements found in bacterial cytoplasm—can be transferred from one bacterium to another by cell-to-cell contact. The result is that bacteria that have never been exposed to antibiotics can become resistant simply by coming into contact with MDR bacteria. If such resistance is transferred to any of the bacterial pathogens causing infections (such as cholera and dysentery) that are common outside the hospital setting, the researchers caution, "most of the presently available antibiotics will be futile against the infectious organisms." ("Hospital Effluent: A Source of Multiple-Drug-Resistant Bacteria," *Current Science* 79, 2000)—*Maria Ribaudo*

UNIVERSE

Radio Bubble

Alien couch potatoes? It's possible, thanks to escaping TV and radio signals.

By Neil deGrasse Tyson



In the opening scene of the 1997 film *Contact*, a virtual camera executes a controlled, slow pullout from Earth to the outer reaches of the universe. For this journey, you can decode Earth-based television and radio broadcasts that have escaped into space. Initially you hear a cacophonous mix of loud rock music, newscasts, and noisy static, as though you were listening to dozens of radio stations simultaneously. As the journey progresses out into space, and as you overtake earlier broadcasts that have traveled farther, the discordance lessens and the signals report historical events that span the broadcast era of modern civilization. Amid the noise, you hear—in reverse sequence—sound bites from the space shuttle *Challenger* disaster of January 1986; the Moon landing of July 1969; Martin Luther King's "I Have a Dream" speech, delivered in August 1963; President John F. Kennedy's January 1961 inaugural address; President Franklin D. Roosevelt's December 1941 address to Congress, asking for a declaration of war; and Adolf Hitler's speech given at the opening ceremonies of the 1936 Olympics. Eventually the human contribution to the signal disappears entirely, leaving a din of radio noise emanating from the cosmos itself.

Poignant. But in fact, this scroll of acoustic landmarks would not unfurl exactly as you hear it. If you somehow managed to violate an important law of physics by traveling fast enough to overtake a radio wave, few words would be intelligible, because you'd hear everything played backward. Furthermore, we hear King's famous speech as we pass the planet Jupiter—an audio-video moment implying that Jupiter is as far as the broadcast has traveled. In fact, King's speech passed Jupiter thirty-five minutes after he delivered it.

Contact's opening scene was nonetheless poetical and powerful, as it marked the extent to which we have presented our modern lives to the rest of the Milky Way Galaxy. The radio bubble, as it has come to be called, centers

on Earth and continues to expand at the speed of light in every direction, while its middle gets continuously refilled by modern broadcasts. Our bubble now extends nearly a hundred light-years into space. Its leading edge corresponds to the first artificial radio signals that ever escaped from Earth, and its volume now contains about a thousand stars, including Alpha Centauri (4.3 light-years away), the nearest star system to the Sun; Sirius (10 light-years away), the brightest star in the nighttime sky; and every sunlike star around which a planet has thus far been discovered.

Not all radio signals escape our atmosphere, however. The plasma properties of the ionosphere, beginning at more than fifty miles up, enable it to reflect back to Earth all radio-wave frequencies of less than about twenty megahertz. This allows some forms of radio communication, such as the well-known shortwave frequencies of ham radio operators and the BBC World Service, to reach thousands of miles beyond their transmitters' horizons. All the broadcast frequencies of AM radio are also reflected back to Earth, accounting for the extended range these stations enjoy.

But if you broadcast at a frequency that isn't reflected by Earth's ionosphere (or if Earth didn't have an ionosphere), your radio signals would reach only those receivers in its line of sight. Tall buildings give a significant advantage to radio transmitters mounted on their roofs. While the horizon for a 5'8" person is just three miles away, the horizon seen by King Kong as he climbed atop New York City's Empire State Building was more than fifty. After the filming of that 1933 classic, a broadcast antenna was installed there. An equally high receiving antenna could, in principle, be located fifty miles farther still, enabling the signal to graze the treetops at the fifty-mile horizon, thereby extending the signal's reach to a hundred miles.

The ionosphere reflects neither FM radio nor broadcast television, itself a part of the radio spectrum. Each of these travels no farther on Earth than the most distant receiver it can see, allowing cities that are relatively near each other to command separate audiences for their own television programs. For this reason, locally broadcast, unsyndicated TV and FM radio cannot possibly be as influential as AM radio, which may account for AM's preponderance of politically acerbic talk shows. But the real influence of FM and TV may not be terrestrial. While their signals are purposely broadcast parallel to the ground, part of every signal leaks straight up, crosses the ionosphere and travels through the depths of space. For these signals, the sky is not the limit. And unlike some other bands in the electromagnetic spectrum, radio waves have excellent penetration through the gas and dust clouds of interstellar space. For them, the stars are not the limit either.

As the signals move away from Earth, they get weaker and weaker, ever more diluted by the growing sphere of space through which they travel.

If you add up all the factors that contribute to Earth's radio signature—such as military radar; the total number of shortwave, AM, FM, and TV stations; the distribution of stations across the planet's surface; the energy output of each station; and the bandwidth over which the energy is broadcast—you find that television accounts for the largest sustained flux of radio signals emanating from Earth. One part of a TV signal's anatomy is skinny; the other is wide. The skinny, narrowband part is the video carrier, through which more than half the total energy is broadcast. A mere 0.1 hertz wide in frequency, the signal establishes the station's location on the dial (the familiar channels 2 through 13) as well as the existence of the signal in the first place. A low-intensity, broadband signal 5 million hertz wide surrounds the carrier at higher and lower frequencies and is imbued with modulations that contain all the program information.

As you might guess, the United States contributes more than any other nation to Earth's global television profile. An eavesdropping alien civilization would first detect our strong carrier signals. If the aliens continued to pay attention, they would notice periodic Doppler shifts (alternations between lower and higher frequencies) in these signals every twenty-four hours. They would also notice the signal getting stronger and weaker during the same time interval. The aliens might first conclude that a mysterious, though naturally occurring, radio loud-spot was rotating in and out of view. But if they managed to decode the modulations within the surrounding broadband signals, they would gain immediate access to elements of our culture.

Unlike sound waves, electromagnetic waves (including visible light and radio waves) do not require a medium to travel through. Indeed, they are happiest moving through the vacuum of space. So the time-honored flashing red sign in broadcast studios that says "On the Air" could justifiably read "Through the Space," a phrase that applies especially to the escaping TV and FM frequencies.

As the signals move away from Earth, they get weaker and weaker, ever more diluted by the growing sphere of space through which they travel. Eventually the signals drown in the ambient radio noise of the universe—noise from regions of star formation in the Milky Way, exotic galaxies, cosmic rays, and the big bang itself. These factors, more than any others, will limit the ability of a distant civilization to decode our way of life.

At current broadcast strengths from Earth, aliens using human technology would require a radio receiver 15 times the collecting area of the thousand-foot Arecibo radio telescope (the world's largest telescope) to detect a television station's carrier signal from a hundred light-years away. If they wanted to decode our programming information, and hence our culture, they would first need to compensate for the Doppler shifts caused by Earth's rotation on its axis and by its revolution around the Sun before they could lock onto a particular TV station. They would then need to have a detection capacity 10,000 times greater than that needed to detect the carrier. In radio-telescope terms, this amounts to a dish with a diameter about 400 times Arecibo's, or about seventy-five miles across.

Electromagnetic waves are happiest moving through the vacuum of space.

If technologically proficient aliens are indeed intercepting our signals (with a suitably large and sensitive telescope) and if they are managing to decode the modulations, then the basic features of our culture are surely befuddling the anthropologists among them. As they watch us becoming a radio-transmitting planet, their attention might first be flagged by early episodes of *The Howdy Doody Show*. Once they knew to listen, they could then audit episodes of *The Honeymooners* and *I Love Lucy* and learn how typical human males and females interact. They might then assess our intelligence from episodes of *Gomer Pyle* or *The Beverly Hillbillies* and then, perhaps, from *Hee Haw*. If the aliens didn't just give up at this point, and if they chose to wait a few more years, they would learn a little more about human interactions from Archie Bunker in *All in the Family*. After a few more years of study, their knowledge would be further enriched by the odd characters in *Seinfeld* and, of course, the prime-time cartoon *The Simpsons*. (They would be spared the wisdom of the hit show *Beavis and Butthead* because it existed only as a cable program on MTV.) These cherished sitcoms were among the most popular shows of our time, each sustaining cross-generational exposure in the form of reruns. Mixed in among our cherished sitcoms would be the extensive, decade-long news footage of bloodshed during the Vietnam War, as well as coverage of Nicaragua, Iraq, Bosnia, and other military hot spots around the planet.

After watching fifty years of television, the aliens could draw no other conclusion but that most humans are neurotic, death-hungry, dysfunctional idiots.

In this era of cable TV, even broadcast signals that might otherwise have escaped the atmosphere are now delivered via wires directly to our homes. If this trend continues, there may come a time when television is no longer a broadcast medium, causing our tube-watching aliens to wonder whether our species had gone extinct.

For better or for worse, however, TV signals are not the only ones from Earth that aliens might decode. Anytime we communicate with our astronauts or our space probes, all signals that do not hit the craft's receiver are lost in space forever, though the efficiency of such communication has been greatly improved by modern methods of signal compression. In the digital era, it's all about bytes per second. If you devised a clever algorithm that compressed your signal by a factor of ten, you could communicate ten times more efficiently, provided the person or machine on the receiving end of the signal knew how to undo your secret signal. Modern examples of compression utilities include those that enable fast modems, MP3 acoustic recordings, JPEG images, and MPEG movies for your computer.

The only radio signal that cannot be compressed is one that contains completely random information, making it indistinguishable from static. And the more you compress a signal, the more random it looks to someone who intercepts it. A perfectly compressed signal will, in fact, be indistinguishable from static to everyone except the person with the knowledge and resources to decompress it. What does all this mean? If a culture is sufficiently advanced and efficient, then evidence of its intelligence might just disappear completely from the highways of cosmic gossip.

Ever since the invention of electric light, human culture has also created a visible bubble. Our nighttime signature has slowly changed from tungsten incandescence to other sources of light, including neon from billboards and sodium from the widespread use of sodium vapor lamps for streetlights. But apart from the Morse code flashed by shuttered lamps from the decks of ships, we typically do not send visible light through the air to carry signals, so our visual bubble isn't interesting. It's also hopelessly lost in the visible-light glare of our Sun.

Rather than let aliens listen to our embarrassing TV shows, why not send them a signal of our own choosing, demonstrating how intelligent and peace-loving we are? This was first done in the form of engraved gold plaques affixed to the sides of four unmanned planetary probes: *Pioneer 10* and *11* and *Voyager 1* and *2*. All four plaques display pictograms conveying some basic science and our location in the Milky Way Galaxy. The two *Voyager* plaques also contain audio statements about the kindness of our species. Traveling at 50,000 miles per hour—a speed in excess of the solar system's escape velocity—these spacecraft are moving through interplanetary space at quite a clip. But compared

with the speed of light, they're ridiculously slow and won't get to the nearby stars for another 100,000 years. These probes represent our "spacecraft bubble." Don't wait up for them.

A better way to communicate is to send a high-intensity radio signal to a busy place in the galaxy, such as a star cluster. This was first done in 1974 when, as a test of the concept, the Arecibo telescope was used in reverse—to transmit rather than to receive. It sent the first radio-wave signals of our own choosing out to space. That message is now headed in the direction of the spectacular globular star cluster known as M13, among the stars tracing the constellation Hercules. The message contains in digital form some of what appeared on the *Pioneer* and *Voyager* plaques. In 25,000 years, when the signal arrives, those intelligent aliens living on M13's planets will know how smart we are.

But there are two problems: The M13 cluster has such a meager quantity of heavy elements (the raw materials of planets) that planets are probably rare among its stars. Furthermore, the globular cluster is so chock-full—it has about half a million tightly packed stars—that any planets it does have would have unstable orbits. A planet's gravitational allegiance to its host star would be challenged every time the star passes through the cluster's center.

In any case, the leading edge of our "on purpose" radio signals (which form directed radio cones instead of bubbles) is now twenty-seven light-years away. If intercepted, it may mend the image of us that the aliens would have deduced from our television shows. But this will happen only if they can somehow determine which signals come closer to what our cosmic reputation deserves to be.

Astrophysicist Neil deGrasse Tyson is the Frederick P. Rose Director of New York City's Hayden Planetarium and a visiting research scientist at Princeton University.

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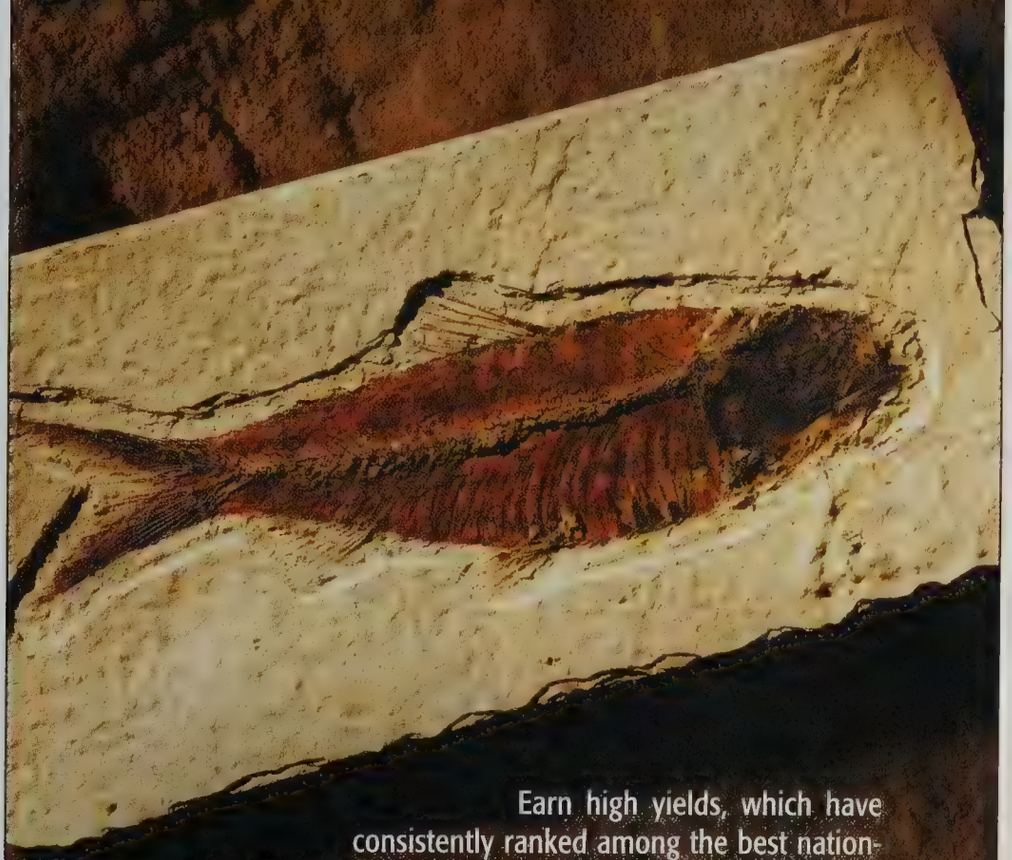

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THIS LAND

Of Water and Wire Grass

A placid river meets a threatened prairie, and a botanist rejoices.

By Robert H. Mohlenbrock

DAVID ORTIZ

Cabbage palms

Rising near the former settlement of Myakka Head, the Myakka River of peninsular Florida flows roughly south toward the town of Port Charlotte, where it empties into the north end of Charlotte Harbor. Along the way, it rolls through the low flats of Myakka River State Park's 28,800-plus acres. One of Florida's largest, the park has precious reserves of disappearing native habitat, which are elsewhere being gobbled up by expanding cities.

The threats are not new. A century and a half ago dry prairie, covered with wire grass, carpeted much of the land from Lake Okeechobee southward, but settlers cleared the prairie and planted crops and a variety of exotic grasses. Little remains today of Florida's dry prairie; only three tracts cover more than 10,000 acres. The stretches surviving in Myakka River State Park—comprising about a third of the park's total area—are among the most extensive dry prairies remaining in southern Florida.

Crop plants and foreign grasses have not been the only causes of its disappearance. Before 1970, park management suppressed fires, thus allowing foreign shrubs (which burning would have eliminated) to invade the area. These aliens created too much shade for prairie plants that need full sunlight to survive. Now, however, controlled burns are helping dry prairies, which the Nature Conservancy designates as globally imperiled, to recover in the park.

One of the park's least threatened features is the lay of the land. A mountaineer would hardly call the topography spectacular: flat expanses, a lot of water, and a fair bit of

pockmarked Florida limestone define the local habitats. With the exception of the DeSoto Plain on the east side of the park, where a few sandy ridges climb to nearly forty-five feet above sea level, the land here sits about fifteen feet above sea level. In September, toward the end of the rainy season, water levels rise, often causing floods along the riverbanks and around the park's two lakes, the Upper and the Lower Myakka. For much of the year this water fills widespread marshes, which dry out only in late winter and spring. Visitors interested in wetland vegetation will have a field day in the habitats that border both lakes.

Where the river brings enough water to sustain trees, a variety of sylvan landscapes flourish. These include moist (mesic) flatwoods, scrubby flatwoods, forested wetlands, and oak-palm hammocks, which host tropical shrubs not found in temperate regions of the United States.

For visitor information, contact:
Park Manager
Myakka River State Park
13207 State Road 72
Sarasota, FL 34241
(941) 361-6511
www.myakka.sarasota.fl.us

Whatever the fate of the areas surrounding Myakka River State Park, much of the land within is relatively pristine. However, considerable damage has been wrought along the park's main roads and wherever feral pigs roam, tearing up the soil and vegetation. On my family's first visit there, about thirty-five years ago, we encountered Rosie, a pig that seemed to relish visitors to her territory. Although everyone got a kick out of seeing Rosie root around and hearing her snort, she and her fellow swine were causing irreparable damage to parts of the park. Both the pigs and the roads have contributed to the proliferation of a number of weedy species.

Many park visitors, however, come for a look at the wildlife typical of the area rather than at the descendants of escaped farm animals. Roseate spoonbills sometimes visit the park and have been seen near the bridge over the Myakka River, and herons, egrets, and ibises flock there. Sandhill cranes are often present in the marshes near the Birdwalk, a boardwalk on the eastern shore of Upper Myakka Lake. Alligators abound.

The park is located about nine miles southeast of Sarasota. Nearly forty miles of trails make most of the habitats accessible to hikers, and the Visitor Center has exhibits on wildlife and their environments. Ranger-guided tours, fishing, biking, canoeing, and camping are also available.

Robert H. Mohlenbrock, professor emeritus of plant biology at Southern Illinois University, Carbondale, explores the biological and geological highlights of U.S. national forests and other parklands.

HABITATS

Dry prairie consists mainly of grass species, especially little bluestem, splitbeard bluestem, wire grass, bottlebrush threeawn, Indian grass, and slender beardgrass. Among the prairie wildflowers are blazing-star, pine lily, vanilla leaf, yellow-eyed grass, Saint-John's-wort, and silk grass (actually related to golden asters). Scattered shrubs include two kinds of low-growing blueberries and the dwarf live oak, which is less than a foot tall.

Wild coffee

KEN BRATE: PHOTO RESEARCHERS, INC.

Invasive shrubs include saw palmetto, wax myrtle, gallberry, fetterbush, and staggerbush. Para grass, which cattle ranchers planted before the land became a park, has become well established, too.

Moist flatwoods occur, for the most part, as islands in the vast dry prairies, although larger, continuous moist flatwoods can be found in the southern part of the park. Where soils are well drained, longleaf pine dominates. Here at the southern end of its range, this pine is widely spaced, giving this habitat, with its more open understory, an appearance reminiscent of an urban park. In wetter soils, slash pine replaces most longleafs.

The presence of shrubs and ground plants in the flatwoods depends on the frequency of fire. One might find fetterbush, staggerbush, the two lowbush blueberries, dwarf live oak, and winged sumac—which also grows throughout the eastern United States. On the ground are dry-prairie plants, which include wire grass, little bluestem, and Florida paintbrush.

Summer wildflowers include meadow-beauty, marsh pink, wild pea, and round-leaved rattlebox (whose seeds, which are loose in the pod, rattle when the pods are shaken). In the autumn, net-veined aster and hollow-stemmed goldenrod add flashes of white and yellow, respectively.

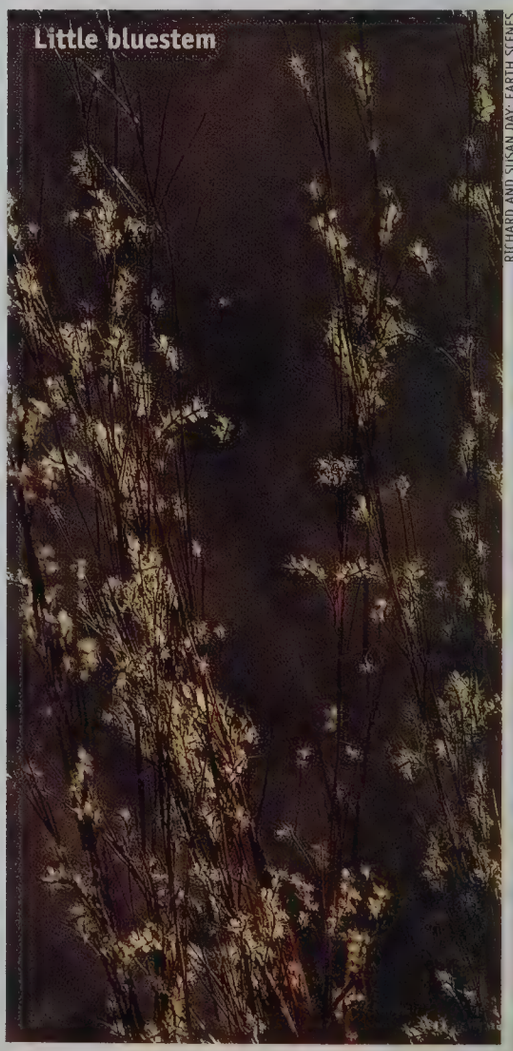
Scrubby flatwoods standing on some of the well-drained sandy ridges at the park's highest elevations host three species of ten- to twenty-foot-tall oaks beneath a canopy of longleaf pine. Myrtle oak, turkey oak, and Chapman oak are often so densely spaced that few other plants can grow beneath them.

Oak-palm hammocks are home to the tall, beautiful cabbage palm, a hallmark of these fertile raised regions on the Myakka River floodplain. Large golden polypody ferns grow in the axils between the firm bases of the palm's leaf stalks and its trunk, which is also adorned with the shoestring fern. Trees well suited to the periodically inundated floodplain include live oak, laurel oak, American elm, and water locust. Tropical plants here include two species of wild coffee, pigeon berry or rouge-plant, prickly ash, marlberry, and colicwood. The wild coffee plants have strong-veined leaves like those of true coffee trees. Pigeon berry has a common relative—pokeweed, or pokeberry—found both in the temperate regions of the United States and in the park. The tropical prickly ash has a temperate equivalent called the toothache tree. Marlberry and colicwood belong to the strictly tropical family Myrsinaceae. Shrubs here are storax, beautyberry, and small-leaf viburnum. Frequent flooding and intense shade limit the herbaceous growth to a few species, although the hottentot fern is usually present.

Forested wetlands generally lie between oak-palm hammocks and the park's rivers and streams. Laurel oak, red maple, and swamp gum dominate. Swamp bay, loblolly bay, and swamp dogwood are plentiful; the Virginia chain fern and the swamp fern are almost always present. Jack-in-the-pulpit grows here and there.

Marshes, with maiden cane and wild millet grasses as two of the dominant species, also contain an assortment of sedges, rushes, and smartweeds. Two lovely blue-flowered lobelias are found here. Para grass has overrun some of the marshes.

Lakes and ponds have buttonbush, pickerel weed, bulltongue arrowhead, horned bladderwort, water milfoil, and water-shield growing in the water.


Little bluestem

RICHARD AND SUSAN DAY; EARTH SCENES

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A Superlative Penguin

The least known, last studied, strangest penguin takes a scientist on a most uncomfortable journey.

Story and photographs by Lloyd Spencer Davis

One of five penguin species with distinctive headdresses, erect-crested penguins sport flamboyant golden "eyebrows." These birds nest on the Antipodes Islands and other remote bits of land in the remote South Pacific.

The Antipodes Islands are in the middle of nowhere. More precisely, they are three and a half days of vomiting southeast of my home in Dunedin, New Zealand. I am the sort of person who gets motion sickness on escalators, and as I lay strapped into my bunk on the *Breaksea Girl,* I asked myself over and over, "Why am I doing this?"

The answer was penguins. Of the world's sixteen species, all have been studied in detail except one. I was after the last, the erect-crested penguin. This penguin owes its anonymity more to its location than to any lack of cuteness or scientific interest. Erect-crested penguins breed on the Antipodes and on a similarly isolated group of islands nearly 200 miles to the north, the Bounty Islands. Both are home to little more than seabirds, seals, and shipwrecks.

Erect-crested penguins are, quite simply, the most striking of penguins. Upright parallel combs of blonde feathers sit incongruously above their eyes, like Marilyn Monroe's eyebrows on steroids, lending the penguins a feminine beauty. But what drew me most to these birds was that they were rumored to exhibit an extremely bizarre behavior. There had been only two prior attempts to study these penguins scientifically—one conducted about thirty years ago, late in the breeding season, and a more recent one lasting a mere five days, during the period of egg laying. The authors of this last study asserted, remarkably, that these penguins, which lay two eggs, deliberately eject the first egg from the nest soon after it is laid.

NEW ZEALAND
North Island
South Island
Chatham Islands
Snares Islands
Bounty Islands
Auckland Islands
Antipodes Islands
Campbell Island
0
500 Miles
JOE LEMONNIER

A colony of erect-crested penguins situated in the lee of a 600-foot-high cliff called Perpendicular Head, above. Right: A small greenish first egg is laid only to be neglected, while the big white second egg gets all the penguin parents' attention.

It was another twist to one of the stranger stories in the animal kingdom. The erect-crested penguin is one of five species known as crested penguins. All five lay two eggs but rear only one chick. Furthermore, in contrast to all other birds, they lay a second egg that is larger than the first, and it is the chick from the second egg that is most likely to survive. Biologists have long sought the answers to two questions: Why produce two eggs if only one chick can survive? Why is the second egg larger? I was, I told myself with each roll of the boat, in search of answers to such questions as much as I was after the "last" penguin.

Late during the fourth night I heard the anchor being let out, and mercifully, the wild pitching eased. I went up on deck to get my first glimpse of the place my two companions and I would be calling home for the next two months. In the morning gloom, I peered straight out at the 600-foot-high cliff aptly named Perpendicular Head. At its base, huge waves crashed relentlessly. I had never seen a place less likely to offer sanctuary, less likely to be called home.

Fortunately, not all the cliffs that surrounded the island were as high as this, but unfortunately, in the small cove that offered the only reasonable landing site, the waves were as fierce as those that pummeled Perpendicular Head. Despite the apparent proximity of the penguins, which I could make out as groups of dots at the base of the cliffs, at that instant they seemed very far away.

We had no alternative but to choose a much less desirable landing site, at Stella Bay. To call our approach a landing is really to glorify it; it was much more like a controlled crash. Wearing wet suits, Martin Renner (a former student of mine), Dave Houston (a biologist from New Zealand's Department of Conservation), and I jumped from a dinghy into the freezing water. A wave immediately slammed us into the rocks, cutting open my knee. We grasped kelp to anchor us, so as not to be taken out in the backwash, and clambered over its slimy fronds to the jumble of boulders that constituted the beach. We then had to wade back in and retrieve repeated dinghy-loads of gear that were tossed to us between one wave and the next: packs of clothes, boxes of food, drums of fuel, generators, scientific equipment, and wood for mending a hut constructed on the island about a century earlier to shelter castaways. By the time we had finished, we were all cut and bruised. After tossing us a box of sandwiches, the captain of the *Breaksea Girl* waved good-bye and steamed off to the northwest, leaving the three of us—the entire human population of the Antipodes Islands—in an enveloping drizzle.

Next we had to get our gear up a 70-foot-high cliff; carry it through waist-high tussock grass, which is just about impossible to walk through without falling over every few steps; and, finally, wade through a bog. It took us two full days of backbreaking work to lug all our supplies up to the hut.

While completing this task,

we were able to make our first casual observations of the penguins. Stella Bay is home to a colony of about 300 breeding pairs. At this stage, however, virtually all those present were single males, which typically arrive at the colony a week or more before the females. Why they should do so is not at all clear; it's not as if they have a swag of boxes and generators to hoist up to their nest sites before get-

The rogue male fur seal grabbed a penguin and shook it so violently that its head came away from its body.

ting down to the business of courtship. The classic explanation is that they come early to secure a site before the females get there, but other penguins manage this without the need for the males to arrive so far ahead of the females. It is said that the males use this period to fight like gladiators for nest space, with the victors presumably getting the choicest sites. But we saw little evidence of this; there was hardly any fighting at all.

It would be wrong to assume from this that male erect-crested penguins are not territorial. They will defend their chosen site if they have to, even at their own peril. The biggest fight we observed was between a male fur seal and a male penguin. The fur seal lunged at the penguin on its nest, shook it vigorously, and tossed it about fifteen feet away. With a deep wound to its chest, the penguin made the mistake of returning to attack the big hairy intruder. This time the seal reached down, grabbed the penguin, and shook it so violently that its head came away from its body. To our surprise, the seal—supposedly a fish eater—set about devouring its foe. A quick check of the colony revealed five similar carcasses. This had been no crime of passion but the premeditated act of a serial killer. We envisaged this rogue seal slowly eating his way through the entire Stella Bay colony as the breeding season progressed. Fortunately for the penguins, two days later a group of elephant seals arrived, banishing the

Cry havoc: Like a bull in a china shop, a young elephant seal throws his weight around a nesting colony, causing alarm.

much smaller fur seals to the nether regions of the beach, and the carnage stopped.

We chose to study the penguins breeding in Anchorage Bay, in the lee of Perpendicular Head. Our main study colony was situated atop a rock stack, and from a knoll above it we were afforded an unimpeded view of all the nests—the perfect place to make observations. But first we had to measure and mark the penguins so that they could be recognized individually. Penguins really do all look alike.

Testosterone-driven behemoths, mature bull elephant seals battle savagely for dominance and mating opportunities. The penguins' courtship rituals are tame in comparison.

The birds proved to be remarkably unperturbed by our presence. We set up shop near the colony and began a processing operation. First I would catch a penguin, using a fishnet like those used to land trout. It was a relatively easy task to approach a penguin quietly and let the net fall gently over it, pulling the bird toward me as I did so. I had to be fairly deft with the next bit: grabbing the penguin around the ankles with my left hand and then quickly grasping the back of its neck with my right. These penguins have sturdier bills than most others. The top mandible ends in a vicious hook that is used to grasp fish but that is quite capable of ripping open your arm or any other part of your anatomy within striking distance. I would carry the penguin to Martin and Dave, who would weigh it; place a numbered stainless-steel band on the right flipper; and measure foot, flippers, bill, and crest. I then took a small blood sample from a flipper, and Mar-

Two giants reared up and faced each other, their noses quivering like jelly-filled socks, their mouths wide open.

tin photographed the crest. Finally, I painted both a letter and a number on its back in white enamel so the individual could be recognized from a distance. This was the key to our behavioral study, because it meant that we would never need to handle the penguin again. Each bird could be completely processed in this way in less than five minutes. In all, we marked 271 individuals before beginning to observe the colony continuously throughout the daylight hours.

The first thing we noticed was that not a lot happened. Even after all the females had arrived and most males were paired up, these guys were positively lethargic compared with other penguins I had studied. The most riveting thing to happen during the entire courtship period occurred on the shoreline in front of us.

A big bull elephant seal had been lying there sleeping when another cruised up like a submarine, inflating its huge proboscis and blowing bad breath in a deep growl. Our erstwhile beach companion raised its head and inflated its own nose. The seal in the water caterpillared up the stones, and the two giants faced each other, their bodies bent at right angles, their noses quivering like jelly-filled socks, their mouths wide open. For a while it seemed that they were going to do battle with their breath—the smell must have been lethal at such a point-blank range.

The intruder flung its head at our resident and bit the side of his body with its huge canine teeth. Our man was no slouch in this department either, and he struck back with a vicious blow to the intruder's back, tearing two parallel, foot-long cuts in its blubber. They continued to trade blows, thumping their chests together and biting each other's body. It seemed an evenly matched contest—until the resident received three unanswered strikes to his right side. Perceptibly, he changed. The intruder leaned more into him; he arched back further. Inch by inch, the intruder shuffled the resident out to sea. In the surf, our guy put up one last stand: bloody open mouths were held close together, and then a final lunge, a final bite, and it was all over.

Now *that* was competition. The mating game we were witnessing in the penguin colony was gentle and benign by comparison. I was used to observing the mating behavior of Adélie penguins in Antarctica, where the courtship period is a frenzy of fighting and fornicating. The erect-crested penguins, in contrast, just did not seem to have their hearts in it. They rarely fought, and whereas Adélie pairs copulate every three hours or so, erect-crested partners consummated their relationship only once every thirty hours. The blood samples we had taken revealed that the males had relatively low levels of testosterone, which might have explained their lack of both aggression and libido. But the females, too, were out of sorts. While female Adélie penguins will copulate within minutes of arriving at the colony and pairing up, female erect-crested penguins were likely to reject a male's initial advances. These penguins seemed to arrive at the colony only half ready to reproduce.

Four fur seals, relegated to the edges of Stella Bay by an incursion of elephant seals, take up vantage points on separate rock stacks.

We settled into a routine of observation stints to watch this protracted, if tame, courtship ritual for clues to the penguins' behavior. After the females had been at the colony for about two weeks, the first eggs were laid. While this signaled an exciting change for us, the penguins were much more blasé: to our surprise, neither mothers nor fathers were inclined to do much about it. Some attempted to incubate halfheartedly, but many simply stood beside the egg and ignored it. Another surprise was that the vast majority of the erect-crested penguins made absolutely no attempt to construct a nest. Other penguins collect stones or grasses to line their nests (ex-

cept king and emperor penguins, which incubate their single egg on their feet), but these birds were content simply to drop their eggs on bare ground or even on the tops of large rocks, often on steep slopes. Without a decent nest, any knock or bump was likely to send an egg rolling away.

In an experiment we conducted in a nearby colony, we created supernests, surrounding some rudimentary nests with large stones so that the first eggs could not roll away. But these survived no longer than those in control nests or in the main study colony. Although the first eggs remained within the vicinity of the nests, they were neglected: some rolled against the rocks, and many broke, probably after being trod on or pecked at.

While her mate is at sea feeding after a long fast, a female incubating her precious second egg is brutalized by a twosome that failed to breed successfully.

We found that about four of every ten first eggs are lost before the second is even laid, but the arrival of the second egg seals the fate of the first. I suspect this is largely for mechanical reasons. The first is not much bigger than a chicken's egg from a supermarket; the second is nearly twice that size. And while first eggs are pale green, second eggs are white. During the five or six days between the laying of the two eggs, the first one—if it survives that long—gets quite dirty as well. A female that has just laid her second egg responds more strongly to the stimulus of the large, bright white egg and will push it into her brood patch, a feather-free area of vascularized skin on her tummy. She will then attempt to draw in the small first egg, but it is like trying to sit on a football and a tennis ball at the same time—an awkward proposition exacerbated by the eggs' aspherical shape, which makes them prone to rolling unpredictably. Females seem to find it difficult to get comfortable. They stand up repeatedly, turning around in the nest and trying to adjust the eggs. Almost inevitably, the smaller of the eggs, being less snug against the female's body, will be dislodged and will roll away. At least another four of every ten first eggs are lost this way on the very day the second egg is laid. And the longest we observed any first egg to survive was six days after the second appeared. But this was not deliberate rejection, as claimed by earlier researchers. Females tested at a colony about half a mile away readily tried to retrieve and incubate a first egg that had rolled away if we replaced it within a few inches of the nest. The combination of parental neglect, differences in egg size, and poor nests seems to conspire against the prospects of the first eggs.

But simply knowing how first eggs are lost does not explain why the penguins persist in laying two eggs and why the second one gets all the attention. Some have suggested that crested penguins lay two eggs because the first is an insurance policy in case the second, larger one is lost. But for erect-crested penguins, at least, this scenario seems ludicrous: more than 80 percent of these so-called insurance policies are lost before or on the day the second egg is laid, and none of the remainder last for more than a week.

Often when one tries to decipher why animals do what they do, a good place to start is with food. Penguins can be divided into two broad groups: those that feed inshore and those that feed offshore. Crested penguins are of the latter kind, swimming just about as far as their flippers can take them to find food and rush it back to the chick. The costs of finding and transporting food over such distances make it unlikely that these penguins could ever bring back enough food to feed two offspring. So why bother laying two eggs? DNA evidence suggests that the ancestors of crested penguins laid two eggs. However, given the circumstances crested

penguins face, surely it would be to the females' advantage to reduce their clutch size by simply stopping their laying after the first egg.

For whatever reason, erect-crested penguins have a long courtship period of two weeks or more. That means that males and females are ashore, and unable to feed, for an extended period of time. While penguins are quite capable of dieting for phenomenally long periods, when it comes to producing the energy and nutrients needed for egg laying, fasting females must convert their reserves of fat and protein, since they can't use nutrients derived directly from food. The little work done on this suggests that erect-crested and other crested penguins depend more upon converting their reserves for manufacturing eggs than other penguins do.

Nests are rudimentary. These penguins are content to drop their eggs on bare ground or even on the tops of large rocks.

Conversion of fats and proteins for egg formation, like most of reproduction, is a hormone-mediated process. Hormones are like chemical postcards that the brain sends around the body to tell it what to do, and it seems crested penguins arrive at the colony with comparatively few of these missives getting delivered to their reproductive system. The synthesis of hormones can be influenced by external events, such as calls made by other penguins or the physical presence of eggs. Indeed, the social stimulation derived from the calling and courting of neighbors in the colony has been shown to hasten the development of eggs in crested penguins.

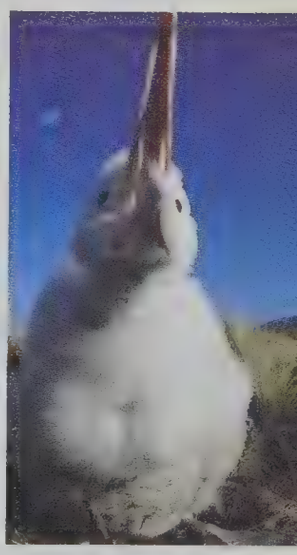
Our results seemed to confirm the benefits of breeding in a crowd. The size of both first and second eggs tended to increase as the colony filled up and became more boisterous. Very early breeding pairs tended to lose their first egg immediately, suggesting that the adults were not ready to care for it properly. The brood patches of both female and male crested penguins take several days to become fully vascularized and suitable for incubation; work by my students on yellow-eyed penguins, the crested penguins' closest living relatives, has shown that the presence of an egg stimulates the development of the brood patch.

As I sat atop the knoll, looking down at pairs of penguins hunkered down on and protecting second eggs, while all about lay the abandoned and broken shells of first eggs, it occurred to me that we were asking the wrong questions about their strange breeding behavior. The real question is not why they have two eggs but why they favor the second egg. Had the first egg been at least as likely to produce offspring as the second, it should have been a relatively simple matter to stop there and reduce the clutch to a single egg. But, of course, to take advantage of the better prospects of the second egg meant having a first one, too, no matter how superfluous that might be.

Could it be that the first is really just a primer for the birds' reproductive system? Had natural selection tilted the balance in favor of the second egg because females were then better able to mobilize their reserves to produce it, and both males and females were better prepared to care for it? If so, then crested penguins have little choice but to lay a first egg even if it has little prospect of producing a surviving offspring. All they can do is reduce its size and the energy they invest in it. To explain why crested penguins favor the second egg, then, is also to explain why they must persist with laying two eggs and why the first is smaller.

Crested penguins' breeding strategy has served them well enough for millions of years. But recently, in the face of environmental changes being wrought by humans all over the Southern Hemisphere, there are signals that all is not well in the crested penguin world: Major population crashes have been recorded for rockhopper penguins.

The islands are also a nursery for other Southern Hemisphere seabirds: A hungry wandering albatross chick sounds off, below, and a light-mantled sooty albatross sits tight on a nest, bottom.



Fiordland penguins are already among the world's rarest. Snares penguins seem to be holding their own but are limited to a single breeding area, making them extremely vulnerable to a local catastrophe. Only macaroni penguins (including a subspecies, royal penguins) appear to be in reasonable health. No truly accurate census of erect-crested penguins exists. However, just over a decade ago there were estimates of 110,000 pairs breeding on the Antipodes, while a few years later the population was estimated to be only half that.

My colleagues and I did not have the time or resources to census all the penguin colonies on the Antipodes, but we did survey and count breeding pairs in representative colonies on the main island. Antipodes Island is less than five miles in length and somewhat more than a mile across at its widest point. It is, however, a desperately hard island to traverse. Its cliffs forbid coastal access, leaving the interior—a tussock-covered plateau—as the only feasible route. The going was particularly tough and the results discouraging: our sampling indicated that the size of the various breeding colonies had fallen between 8 and 41 percent since the counts made three years earlier.

A female driven from her nest by attackers stands muddied and battered, below. Opposite page: A view of Perpendicular Head with an albatross aloft.

Albatrosses are distant cousins of penguins. On the cliffs above the colonies, we encountered nests of the light-mantled sooty albatross; on the plateau, huge wandering albatross chicks sat like white, fluffy lighthouses. Simple economics dictates that albatrosses, too, can never rear more than one of their gargantuan babies and so lay a single egg. However, the albatrosses' strategy has one major advantage over the penguins' when environmental changes affect the distribution and abundance of prey: Albatrosses can fly. Penguins, even offshore-feeding penguins, are much more constrained by how far they can go from the colony and are therefore much more susceptible to local perturbations in the ecosystem.

We do not know just where erect-crested penguins go to find fish, but because a chick must be fed frequently after it hatches, parents must be limited to foraging within a radius of less than seventy-five miles from the colony. The crested penguins' approach to chick provisioning also differs from other penguins'. Whereas in other species the parents take turns getting food for their newly hatched chicks, crested penguins strike a blow for female liberation, with the female being the sole breadwinner for the first two or three weeks, while the male stays at home to look after the chick.

During the period when the eggs are being incubated, erect-crested penguins are likely to travel

The poor females lay over the eggs, flippers spread-eagled, while the marauders meted out blows with flippers and beaks.

hundreds of miles on feeding trips that can last upwards of two weeks. The energy demands of fasting through courtship and producing eggs are high, and in other species of penguins, either the male or the female departs immediately for the feeding grounds after egg laying. Not crested penguins. Parents remain together at the nest for up to ten days or so after laying. This baffled us as we continued to monitor the study colony, because only one parent at a time can incubate the egg—and the male, especially, having already gone without food for about a month, must have been starving. Why should he continue to hang around?

When hunger did eventually force the males to leave (after they had lost some 40 percent of their original body weight), we witnessed yet another twist to this tale: neighboring males and unemployed birds—penguins that either had not bred or had failed to breed successfully—went around attacking the females left alone on their nests. The poor females lay prone over their second eggs, flippers spread-eagled, forehead tucked down onto the ground, eyes closed, while the marauders meted out a flurry of blows with their flippers and beaks. In several cases, a female was forced to abandon her nest, and the egg was broken. Could it be that their male partners had remained with them so long after egg laying to guard them?

As our time on the Antipodes drew to a close, I was beginning to see the erect-crested penguins not so much as the last penguins but as the oddball penguins. Instead of answers, we had found mostly more questions. To unravel their story further, it seemed unavoidable that we would need to return. And as I boarded the *Breaksea Girl* for the journey back to New Zealand, that thought alone was enough to make me ill immediately. □

Altruism in the Outback

For some tiny Australian insects, the willingness to die for one's home is a relative matter.

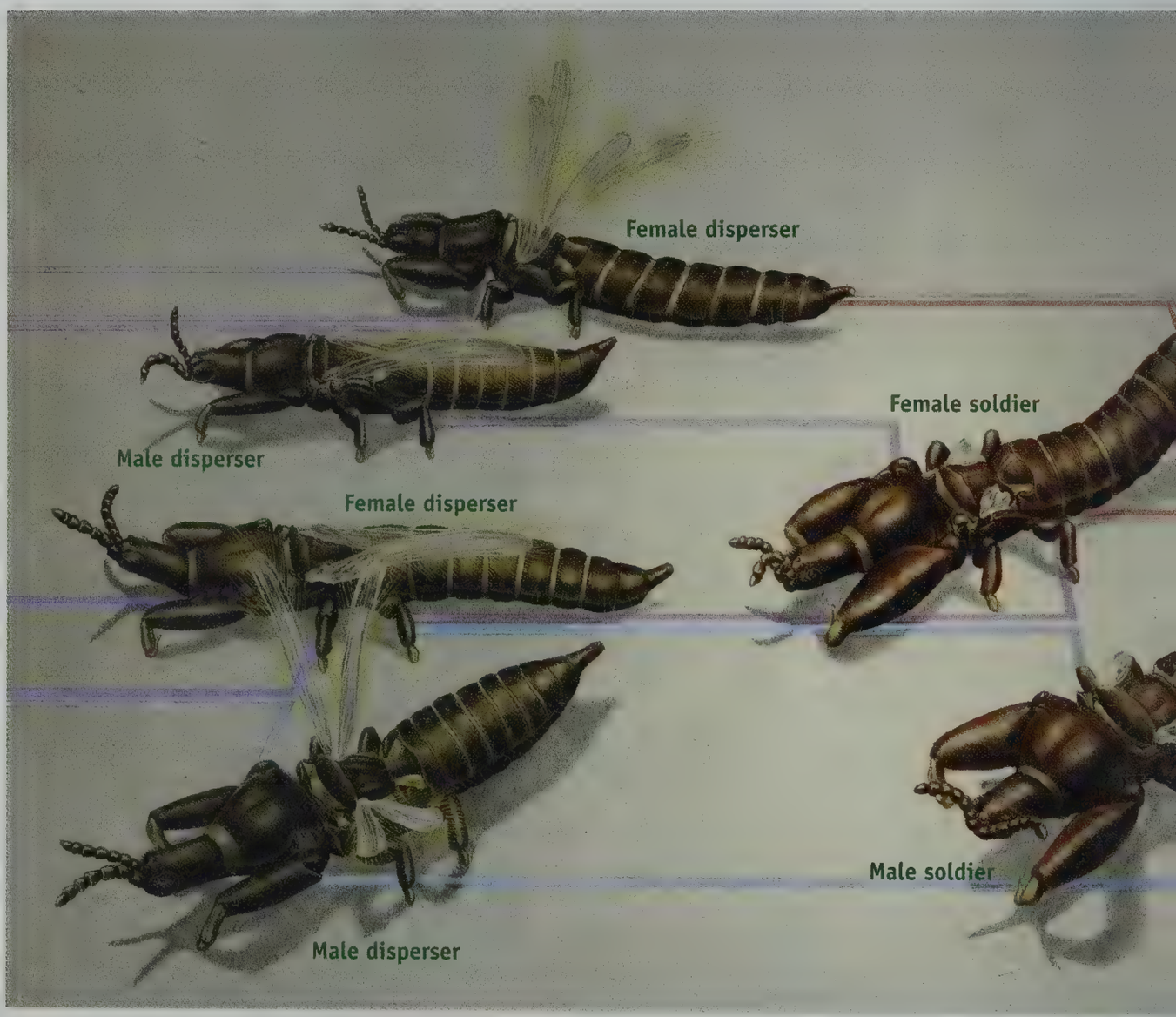
Story by Bernard J. Crespi
Illustrations by Utako Kikutani

A whistle-blower risks her job by speaking out about threats to the environment, a soldier gives his life in defense of his homeland, a New York City firefighter dies in the collapse of the World Trade Center towers as he struggles to save the lives of strangers. Heroic actions like these fill us with deep emotion and pride in the altruistic possibilities of humanity. Yet we are not the only altruists. Termites rush to a breach in their nest and clamp their jaws onto the snout of a marauding anteater, almost guaranteeing their own death. A worker honeybee that stings us to defend her mother and other family members in the hive is doomed, for she cannot extract her barbed stinger from her victim without ripping out her innards in the process. Unlike the human examples, these animal altruists do not perhaps deserve to be called heroic, and they are acting only in defense of their own kin. But both pose a dilemma for evolutionary biology: how can self-sacrifice have evolved if the altruistic individuals so often bring about their own destruction?

For Charles Darwin, this paradox could be resolved by the idea that natural selection operates not only at the level of individuals but also at the level of families. He reckoned that just as farmers can retain a favored trait of domestic animals (such as well-marbled cattle flesh) by breeding relatives of the superior individual, natural selection can preserve and promote seemingly selfless traits of wild

In this cutaway of a gall, a female soldier (the large brown individual in the foreground, with the raised abdomen) grasps a black invader thrips. Also in the gall are other soldiers, eggs, larvae, and several of the soldier's long-winged siblings.

animals—as long as genetic relatives benefit from the act. One hundred years after the *Origin of Species,* the late biologist W. D. Hamilton formalized Darwin's conjecture, developing what is now called kin selection theory. This theory predicts that, all else being equal, the degree of an individual's altruism toward family members should depend on how closely related they are genetically. Most of the time, the real world acts just as Hamilton predicted. But in many species, close relatives in social groups behave selfishly toward one another, and in some species in which groups are not made up of close relatives, altruistic actions are common. To understand how social behavior evolves, we must consider not only genetic relatedness but also aspects of habitat and ecology that may select for altruism.

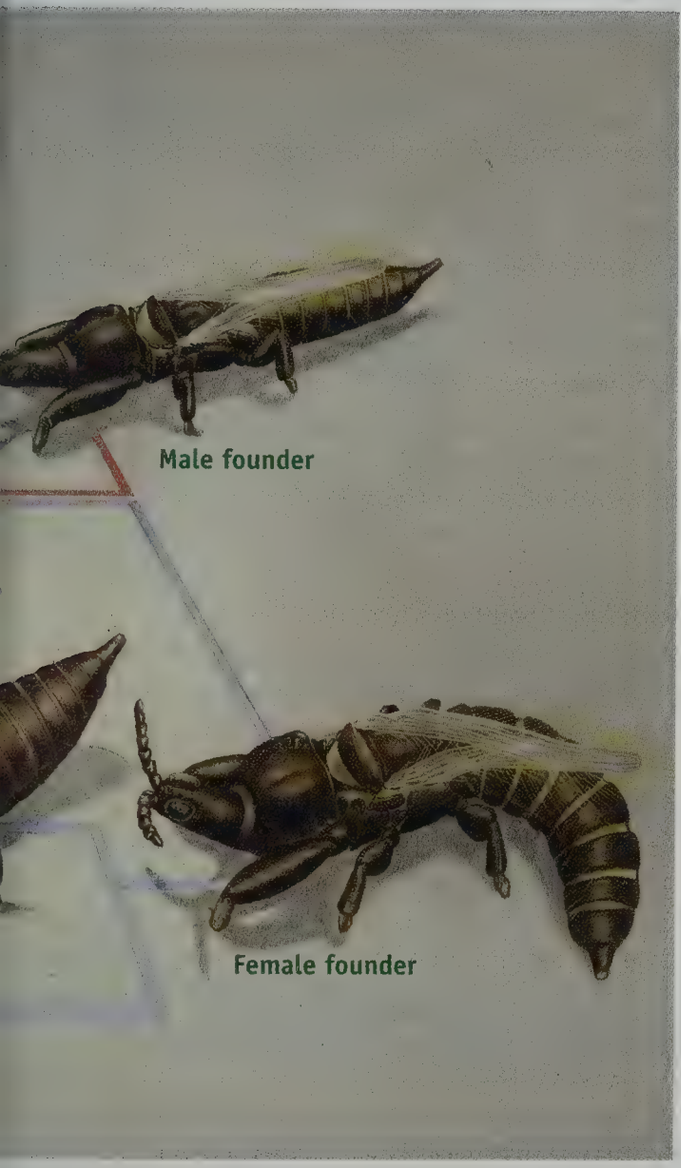


A pedigree shows that social thrips can produce tiny-winged soldiers, which never leave the gall in which they were born, as well as longer-winged individuals, which disperse to produce their own galls. Both dispersers and stay-at-home soldiers can reproduce.

With this goal in mind, I decided to study thrips, a group of punctuation-sized insects (in the order Thysanoptera) most commonly encountered as pests of houseplants. Among the approximately 5,000 described species are thrips ranging in size from 0.5-mm motes to 15-mm giants. All have sucking mouthparts with which they feed on green plant tissue, pollen, spores, or fungal mycelia. I chose to study these insects for two reasons. The first is that in thrips, as in the order Hymenoptera (ants, bees, and wasps), females develop from fertilized eggs and are diploid (having two sets of chromosomes, one from each parent), while males develop from unfertilized eggs and are haploid (having a single set, inherited from the mother). This haplodiploidy, as Hamilton was the first to point out, has important implications for the evolution of altruism. In haplodiploid species, females share 75 percent of their genes with their full sisters: 50 percent via their father (in these species, all the sperm produced by a male are genetically identical) and 25 percent via their mother (she has two alleles, or forms, for each gene, halving the probability of passing on any particular allele). Females can thus pass on their own

genes more effectively by helping to rear and protect full sisters (to which they are three-quarters identical) than by leaving home and producing their own offspring (only one-half identical).

My second reason for focusing on thrips had to do with ecology. About twenty species in the deserts of Australia occupy galls, plant tissues that have been modified by feeding insects to form a hollow cavity. Galls resemble nests, except that neither the mother nor her offspring have to leave to find food: they can get all they need by feeding on the gall's walls. Such all-in-one habitats are extremely valuable to their creators—perhaps worth dying for—and, I thought, would be likely to promote altruistic defensive behavior.



Thus, armed with collection records from the early Australian entomological pioneers, I drove far into the outback to an arid landscape dominated by vast stands of acacia shrubs inhabited by 3–4 mm thrips. Here, on various species of acacia, I found a diversity of gall forms: simple spheres, fat bean shapes, round and flat coin shapes, hemispheres like half a football, thin tubes, and spiky, purse-shaped pouches. The galls ranged in size from 5 mm wide and 15 mm long to 15 mm wide and 60 mm long. All were hollow, with walls 1–2 mm thick.

Over the next several years, I studied the life histories and behavior of the gall inhabitants. A single adult female induces a gall on a young leaf by sucking out the juicy, nourishing cell contents of the plant tissue. Through a mechanism not yet understood but perhaps involving a certain feeding pattern or the injection of chemicals by the thrips, the growing leaf develops a shallow depression at the feeding site. This deepens and closes over the female in a nascent gall. In some species, an adult male accompanies the female, mating with her and joining her in the developing gall, where they will both spend the rest of their lives. In other species, some females are virgins at the time of encasement.

Sometimes a female—presumably after failing to produce a gall on her own—tries to gain one by force. The resident and the challenger fight viciously, sometimes to the death, using forelegs armed with daggerlike "teeth." Rearing up like cobras, they lunge, grasp, and grapple with their forelegs, seeking to plunge their daggers into their opponent's most vulnerable spot: the thorax (the middle section of the insect's three-part body). Rival males may also engage in lethal fights for the privilege of being encased with a female. The stakes are high: females are fighting for their one chance at reproduction, shelter, and a lifetime supply of food; males are fighting for a mate (if they are successful, the only one they will ever have). In some dense populations of thrips, most galls eventually contain not only living, breeding thrips but also the shriveled dead bodies of vanquished rivals.

Female thrips can pass on their own genes more effectively by helping to rear their sisters than by producing their own offspring.

Once all the fighting is over and the gall is more or less closed (though still growing), the female begins to lay eggs on the gall's inner surface. Brood sizes range from about a hundred to more than a thousand, depending on the species. The eggs hatch after about two weeks, and the young larvae begin to feed on the walls of the gall. Juvenile thrips molt through two stages, or instars, before pupat-

ing. In some species, the second-instar larvae leave the gall through very small holes or cracks (located where the gall closed over the foundress) and apparently drop to the ground to pupate in deep cracks in the soil. In other species, the entire brood matures within the gall, dispersing after the gall dries up, drops from the plant, and opens.

But some young thrips follow a very different path. In six Australian species, some or all of the first individuals to develop in a brood never disperse. Instead they remain within the gall and defend it, often to the death, against invaders of other species (including other thrips, caterpillars, and fly and hymenopteran larvae). These "soldier" thrips, which may be male or female, have tiny, useless wings but greatly enlarged forelegs, armed with even bigger daggers than those of their pugnacious, winged mothers. When an incompletely sealed gall is breached—most commonly by a single, specialized, gall-usurping invader thrips—the soldiers rush headlong into the breach and attempt to grab the invader and pierce its cuticle. The invader (also heavily armed and well armored) generally manages to kill one or more of the defenders; sometimes it succeeds in killing them all. When that happens, the usurper proceeds systematically to execute the now defenseless larvae before it deposits its own eggs in the gall. Sometimes, however, the soldiers subdue the invader, enabling their siblings to complete their development in peace until they are ready to fly off and start galls of their own.

Both virginity and incest may have contributed to the evolution of soldiering and altruistic behavior in thrips.

The discovery of altruistic soldiers fits nicely with Hamilton's theory of kin selection, but it raises many more questions than it answers. For the past eight years, working with colleagues in Britain, Canada, and Australia, I have been employing an arsenal of methods to determine how and why soldiers evolved in Australian gall-breeding species. We have sequenced a portion of the mitochondrial DNA in all species of Australian gall thrips. Using the variation in the DNA sequences to construct an evolutionary tree for the group, we inferred that soldiers evolved only once in these thrips, early in their diversification. Other molecular studies—employing molecular markers known as microsatellites to estimate levels of genetic relatedness—enabled us to determine that in all six species that have soldiers, levels of genetic relatedness are sometimes exceptionally high. (Relatedness is partly a function of how often the foundress mates and how closely related she is to her mate or mates.) Thus, we can infer that relatedness was probably high when soldier thrips first evolved, which supports Hamilton's theory that genetic relatedness favors the evolution of altruistic behavior.

Our microsatellite data also indicate that five of the six species with soldiers are incestuous, with brothers and sisters mating in the gall. Soldiers mate with soldiers, and winged males mate with winged females before they disperse. This incest results in offspring that are genetically even closer. Another consequence is that the males in these species can be as highly related to gallmates as females are, which helps explain why there are soldiers of both sexes.

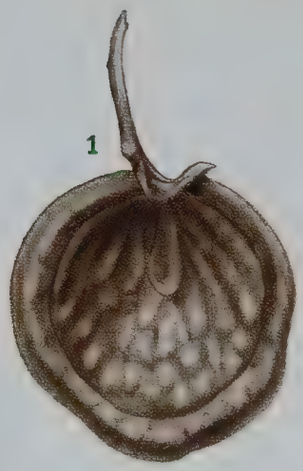
Many soldiers, of course, die in battle before having a chance to reproduce, but we found that, especially in the older species, female soldiers that are not killed defending their gall can lay considerable numbers of eggs. The ability of soldiers to reproduce may have eliminated one impediment to the evolution of altruism, because protosoldiers would not have had to give up on personal reproduction while developing specializations for gall defense. And haplodiploidy means that even unmated female soldiers can lay viable eggs (all of which will produce sons). Thus, both virginity and incest may have contributed to the origin of soldiering.

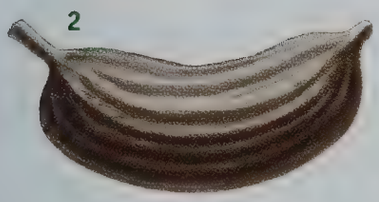
Comparing thrips with other altruistic creatures reveals a number of interesting parallels. Researchers studying bees and wasps often emphasize not only haplodiploid sex determination but also the importance of defense against natural enemies, such as ants and birds, in the evolution of sociality. And many species of gall-inhabiting aphids also have soldiers. Finally, thrips share features with termites—generally considered to be near the pinnacle of insect social life. In many termite species, for example, soldier castes are highly developed, and colony members never leave their nests of dead wood because, like gall aphids and gall thrips, they are able to feed off the walls.

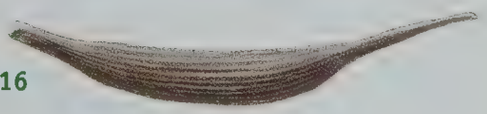
A wide taxonomic gulf will forever separate thrips, aphids, and termites from their human observers. Nevertheless, a shared appreciation of the importance of a home—vital for protecting, nourishing, and raising a family—reminds us of our connection to even such tiny, distant relatives as these insects. □

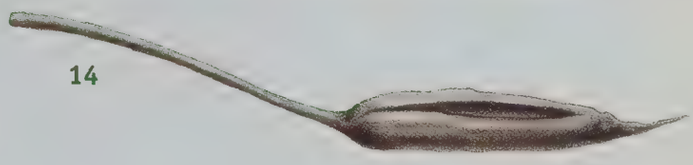
Made-to-Order Galls

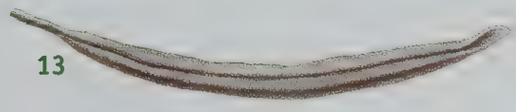
Australian thrips not only induce their acacia hosts to develop galls, they also seem to determine the galls' size and shape. Different species of thrips occupying the same kind of acacia, in fact, produce tremendously different galls (compare 9 and 10, for example). Closely related thrips species tend to make similar galls, regardless of the acacia species on which they find themselves (4 and 9, and 13 and 15, are two such pairs). Species that produce large broods tend to make relatively large, rounded galls, capable of housing up to a thousand thrips (3 and 17, for instance). Species that produce fewer young, as well as species with soldiers, tend to have smaller, more elongate galls. Examples of the latter are 10, 11, 13, and 15.

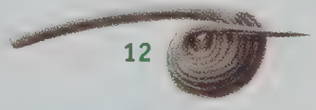


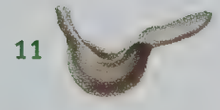


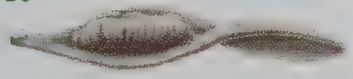


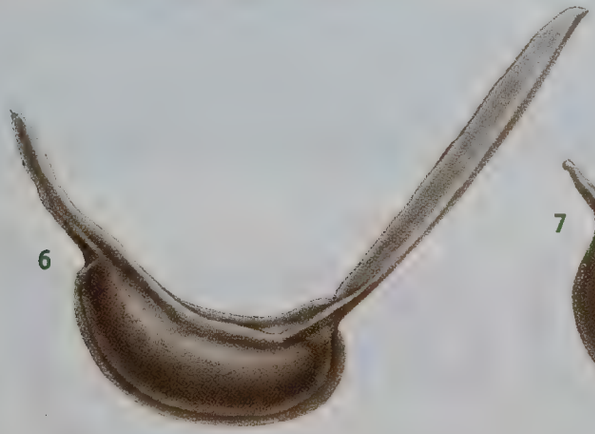




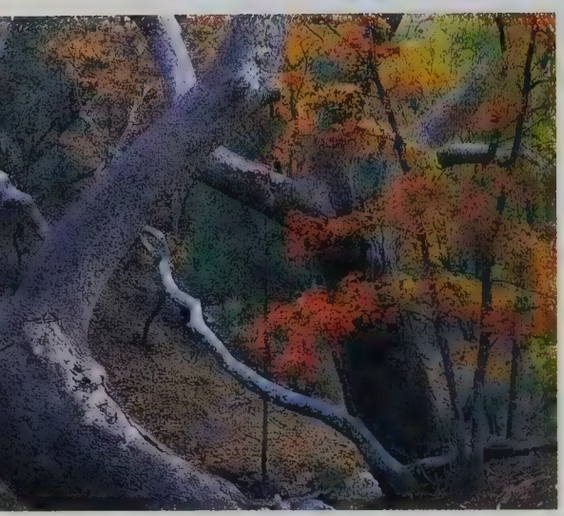








Photographs by Jack Dykinga
Story by Wade C. Sherbrooke



Amid the deserts of Arizona, maples blaze a trail.

Big-tooth maples splash their colors among Arizona sycamores in Ramsey Canyon, above. Agaves in Miller Canyon, right, grow cheek by jowl with the maples, which—unlike succulents—need plenty of moisture to survive.

In the Chiricahua Mountains of southeastern Arizona, I hike through narrow canyons in search of the crimson glory that maple trees bring to autumn. A strange quest, perhaps, here where the Chihuahuan and Sonoran Deserts meet? Only to the uninitiated. The Chiricahuas, Huachucas, and other "sky islands" are ecological isolates in a sea of desert; the clouds that hit these mountains drop up to forty inches of rain a year on them, whereas the surrounding desert receives only about twelve inches. Water trickling down the slopes into canyons supports the southernmost populations of the Rocky Mountain big-tooth maple, also called the western sugar maple.

I know I won't find maples in every canyon, so I choose carefully. Entering Cave Creek Canyon at the spot where its watercourse emerges, I start up the South Fork. Thanks to the summer rains, the beds and sides of the sky islands' watered canyons are home to many plants that could never survive outside in the desert valleys. The Cave Creek watercourse—so weak in the first days of fall that frequently it runs only below the surface—gives sustenance to sycamores, cottonwoods, and Arizona cypresses. I spot a few big-tooth maples as well; I'm

Islands of A

utumn

Crimson-leaved maple branches along a stream in Cave Creek Canyon, right. Below: Maples in Miller Canyon grow close to yuccas. Opposite page: In Cave Creek Canyon, ladybird beetles congregate on an apache pine.

on the right track. Glancing up, I also note a healthy covering of pine, fir, and spruce trees at the summit—a sign that enough rain falls throughout the year to nourish them.

As I move upstream, often hopping over boulders, the canyon narrows. Finally I am in the midst of a big-tooth maple forest. The roots of these water-loving trees have tapped whatever moist soil has accumulated on the bottom of this cut; a rich maple canopy blazes up along the canyon.

Onward I climb, upward, the workload telling on my body. Taking a breather, I observe at one point a quite different world just a few feet away from my red-leaved fastness: rock-rich, water-poor slopes. But even such eroded volcanic remnants are life-giving enough for some plants, and I see a healthy scattering of succulents—yuccas, agaves, sotols, prickly pears—as well as evergreen oak, small-leaved trees adapted to dry conditions.

Big-tooth maples need a more forgiving environment. Enough of them have found it here to blaze small trails of autumn color on the desert slopes of the sky islands. □

A Lost Menagerie

During the past 500 years, countless animal species have gone extinct, some to loud lamentation, others to little notice. Now the art and words of two men have brought to life dozens of the lost creatures, including this sampling—three mammals, a bird, and a reptile—that once lived in Australia and New Zealand.

Story by Tim Flannery ~ Paintings by Peter Schouten

It may seem a soul-destroying task to set about documenting, in words and pictures, the creatures that have perished in the past 500 years, but this project is one of the most exciting I have ever been involved in. That's because it has allowed me to glimpse, in my imagination at least, a tiny flicker of the wonder of this lost world. Over the four years of the project, my collaborator, Peter Schouten, created 103 life-size paintings. Each was a voyage of discovery: even photographs don't exist for most species we studied, and the few that are available are reproduced in black-and-white.

Because it was essential that Peter's images be as accurate as possible, we both made numerous trips to museums. There we would photograph, sketch, and take notes on the faded and distorted specimens. These records, along with other people's written accounts and sketches drawn from life, constituted our reference materials. On occasion, I would find myself descending into the vault of a European museum where rare and valuable specimens are housed. There a curator would unlock a cabinet and open a drawer to reveal, for instance, a stuffed bird skin that the great Captain James Cook himself had seen, the sole example of an entire species. On one memorable occasion at the University of Oxford, the famous head of a dodo (the only one left) was placed reverently in my hands; on another, I peered through an alcohol-filled jar at the sad remnants of a long-extinct fruit bat. To see or touch such specimens seemed to put me in direct contact with a rich, now vanished world.

From *A Gap in Nature: Discovering the World's Extinct Animals,* by Tim Flannery and Peter Schouten. Text © 2001 by Tim Flannery; illustrations © 2001 by Peter Schouten. Reprinted with permission of the publisher, Atlantic Monthly Press.

Greater Short-Tailed Bat *(Mystacina robusta)*

Last record: April 1965. Distribution: prehistorically, North and South Islands, New Zealand; historically, small islands off Stewart Island, New Zealand.

New Zealand was home to only three land mammals before the arrival of the Maori, and all were bats. Two species belonged to a unique New Zealand bat family, of which the greater short-tailed bat was the larger member.

Short-tailed bats are the only bats as adept at scrambling along the ground as they are at flying. They have pouches on the sides of their bodies for their wings to fold into. With their wings hidden away, they can race through burrows or scrub with the alacrity of shrews and mice.

In historic times, greater short-tailed bats were known only from one dubious South Island record and from colonies on several small islands off Stewart Island in the far south. There the bats used the burrows of seabirds as roosts. They flew slowly, never rising more than ten feet off the ground. They fed on nectar from flowering plants and were probably also partly carnivorous, hunting nestlings as well as scavenging fat and meat from muttonbirds caught and left out to dry overnight.

The very last refuges of these bats were on Solomon and Big South Cape Islands, which remained rat-free up to a remarkably late date. The bats thrived there as recently as 1962 or 1963, until the arrival of black rats aboard fishing vessels.

Pig-Footed Bandicoot *(Chaeropus ecaudatus)*

Last record: 1901. Distribution: inland Australia.

The pig-footed bandicoot was one of the very strangest of marsupials. The size of a kitten, it had long, slender limbs, with each hind foot bearing a single, elongated toe like a tiny horse's hoof, and each forefoot bearing two digits that resembled miniature cloven hoofs. It had a peculiar gait, being likened by a nineteenth-century naturalist to "a broken-down hack in a canter, apparently dragging the hindquarters after it."

Pig-footed bandicoots were never common, although the species was rather widespread. They appear to have been principally vegetarian, taking grass seeds in the wild, although in captivity they ate lettuce, bulbs, and grasshoppers. By day they sheltered in a grass nest, from which they emerged in the evening to feed.

Gerard Krefft, a member of the 1856–57 Blandowski expedition to the junction of the Murray and Darling Rivers, brought along a drawing of a specimen to show Aborigines that this was the animal he was eager to procure. Unfortunately, the only drawing he could obtain was of a specimen that had lost its tail, and his Aboriginal helpers brought him any number of common bandicoots with their tails removed. Eventually they arrived with two living pig-footed bandicoots. Krefft, who was on short rations, studied them for some time before he killed one and ate it. He recorded that "they are very good eating, and I am sorry to say that my appetite more than once overruled my love for science."

The Australian nation came into existence through federation in 1901, the same year that the last pig-footed bandicoot specimen was secured. Interviews with Aborigines living in remote regions, however, suggest that the species survived long after this, finally becoming extinct in the western desert as late as the 1950s. Just which factors—the changed fire regime; the introduction of foxes, cattle, sheep, and cats—were responsible for the extinction of this strange creature remains unclear.

Kawekaweau *(Hoplodactylus delcourti)*

Last record: 1870. Distribution: North Island, New Zealand.

Maori legend has it that a giant lizard, known as the kawekaweau, once inhabited New Zealand, the land that the Maori call Aotearoa. The last person to catch one was a chief of the Urewera tribe, who found it living under the loose bark of a dead tree in central North Island in 1870. He described it as being brownish, with red stripes, and as thick as a man's wrist. But no specimen was kept, and the kawekaweau came to be considered by biologists as a legendary or fantastical creature. Then, in 1986, researchers published an article announcing the "discovery" of an ancient stuffed lizard skin, mounted on a plank, that had lain unrecognized in a museum in Marseille, France, for well over a century. No one knew how it came to be there or even when it was collected, for it had no label. The scientists who examined it were amazed: it was by far the largest gecko they had ever seen, being half again as long as the largest previously known species. They eventually surmised that it was a specimen of the kawekaweau, the only one to have survived to give credence to the old Maori tales.

The kawekaweau, which has not been recorded as a living creature for 131 years, must have been an important predator. Since large geckos often consume a broad range of foods, it may have also eaten plants and even served as a pollinator in New Zealand's ecosystem. Unfortunately, it vanished before anything could be learned of its biology. The causes of its extinction remain unclear, but it is likely that rats, weasels, and cats played a role in its demise.

Slender Bush Wren *(Xenicus longipes)*

Last record: 1972. Distribution: North, South, and Stewart Islands and nearby islands, New Zealand.

The slender bush wren was a small bird with poor powers of flight. Although it belonged to a group that comprises the most ancient of songbirds, it was largely silent, emitting only faint rasping sounds as it foraged for insects with its long, slender bill. It built its nests in cavities among tree roots or in fallen logs or clumps of ferns. Both parents incubated the eggs. In habits and ecology, slender bush wrens were more like mice than like birds, and in New Zealand, which lacked mammals except for a few bats, they may have evolved to fill the ecological niche occupied elsewhere by small rodents.

The slender bush wren was rarely seen on North Island at the time of European contact; the last specimens were collected there in about 1850. The birds persisted on South Island until about 1968. Their final stronghold, however, was Big South Cape Island, but when rats reached there in 1962, the wrens rapidly declined.

Broad-Faced Potoroo *(Potorous platyops)*

Last record: about 1875. Distribution: southwestern Australia.

The tiny broad-faced potoroo survived for just thirty-six years after the establishment of Western Australia's Swan River colony, where the city of Perth now stands. Almost nothing is known of its biology. The collector John Gilbert recorded all of our firsthand knowledge of the marsupial (one of a group known as rat kangaroos) in one sentence: "All I could glean of its habits was that it was killed in a thicket surrounding one of the salt lagoons in the interior." It seems to have inhabited a scrubby belt of vegetation between the forests of the southwest and the arid interior.

Just twelve specimens were ever collected. The Australian Museum in Sydney was the only museum in the world to preserve (in spirits) any complete bodies, but in 1913 the museum decided to turn those specimens (which it had held since the 1860s) into study skins. The bodies—with all their potential to inform us about the animal's diet, parasites, organ adaptations, and DNA—were simply thrown out.

It seems likely that either the cessation of Aboriginal burning—done to attract game species and clear the land—or the arrival of cats caused the extinction of the broad-faced potoroo. This creature vanished long before foxes became common in Western Australia or land clearing there by European settlers became widespread. □

Bronze trees and masks evoke the spirit worlds of a lost civilization in China.

The Enigmatic Art *of* Sanxingdui

By Jay Xu

PAUL MACAPIA; SEATTLE ART MUSEUM

Images such as the head on the opposite page and the life-size figure above have no parallels elsewhere in China.

The Red Basin, which falls mostly within southwestern China's Sichuan Province, is an isolated land of plenty. Since antiquity, its fertile soil, mild weather, and abundant water from tributaries of the Yangtze River have made the area rich in vegetation and game and hospitable to human settlement. Yet the basin is surrounded by mountains and high plateaus. "The road to Shu is harder than the road ascending to the blue sky," the eighth-century A.D. poet Li Bo famously said, describing the journey there from the north (Shu was then the common name for the region, now known in China as the Sichuan Pendi). Even today, despite highways and railroads, land travel to and from the basin is not always easy.

When I first visited the Red Basin in 1988—as a student of early China and a young assistant curator then working in the Shanghai Museum—I, too, traveled there from the north. The train ride was sometimes excruciatingly slow; on occasion the train all but ground to a halt as it climbed up a mountain. In places the tracks were laid on narrow paths hewn along precipitous slopes that overlooked river torrents below. Tunnel often followed upon tunnel. In earlier times, the challenging topography was a barrier to contact with other regions, especially the middle Yellow River Valley, 600 miles to the northeast, home to China's first two historic dynasties, the Shang (ca. 1500–1050 B.C.) and the Zhou (ca. 1050–221 B.C.). The period of the Shang and Zhou dynasties largely defines what archaeologists call the Chinese Bronze Age (ca. 2000–300 B.C.). These two powerful societies cultivated such crops as millet, rice, and wheat; established large cities; practiced warfare; and manufactured jade implements and bronze vessels used in making offerings to ancestors. The Shang also developed writing, which the Zhou refined and made more extensive use of, but the records they left behind barely mention Sichuan. Among the surviving examples are inscriptions incised on "oracle bones" (the shoulder blades of cattle and the bottom shells of turtles, used in divination) and dedications to deceased ancestors, impressed on bronze vessels.

The early people of the Red Basin left no written record of their own, further shrouding the region in obscurity and creating a common perception that it was a cultural backwater for most of the Bronze Age. In the last century, however, mainly the past few decades, this impression has gradually been changing, thanks mainly to findings at an archaeological site called Sanxingdui. Located in the

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Sanxingdui has yielded more than one ton of bronze, gold, jade, and stone.

Chengdu Plain on the western edge of the Red Basin, the site is surrounded by lush but rather nondescript farmland, far from the bustle of modern life. On the April day when I first saw the site, the yellow rape flowers were in full bloom, and the place made me feel vibrant and sleepy at the same time. Little did I know that the striking objects that had been unearthed there would become a major focus of my professional life.

Hints that the locale was important in the past had surfaced as early as 1929, when a local farmer found a pit containing several hundred jade and stone artifacts. An archaeological field survey in 1951 revealed that such ancient cultural remains were distributed over a considerable area. Between 1980 and 1985, researchers unearthed jade implements, a pottery kiln, and extensive house foundations, indicating that a settlement of substantial size existed there from about 2500 to 1000 B.C.

SICHUAN PROVINCIAL INSTITUTE OF ARCHAEOLOGY

The 1,300 artifacts in Sanxingdui's Pit 2, above, were placed in distinct layers and topped by 67 elephant tusks. Right: The ancient settlement was located in a fertile, well-watered area.

Beginning in 1985, archaeologists uncovered remnants of what seemed to be the boundaries of a city—pounded earthen walls from 20 to 30 feet high, 130 feet thick at the base, and narrowing to 60 feet at the top. These had been constructed starting in about 2000 B.C. Evidently the city once had at least three walls—on the east, south, and west sides—surrounding an area of at least one and a half square miles, huge for the time. Some archaeologists think that a wall once also existed on the north side but that it was washed away after the settlement was abandoned.

While such formidable walls may suggest a defensive purpose, functional weapons are conspicuously absent at Sanxingdui (by contrast, the weapons found at the Bronze Age sites in northern China testify to the Shang and Zhou concern with military defense). With their gently sloping sides, Sanxingdui's walls may instead have been dikes for flood control. Among the cultural deposits found near the walls (which contained pottery fragments and other broken artifacts) are layers of blackish silt: possible deposits from floods.

Investigations both inside and outside the city walls have revealed the foundations of a number of buildings. The largest—a 2,000-square-foot complex with several rooms—might have served as a gathering place and ritual center. Elsewhere the remains of workshops and kilns suggest a large population requiring the services of specialized artisans. At its height, in about 1200 B.C., the entire settlement covered almost five square miles.

What has primarily thrust this civilization into the consciousness of historians of China, however, is the excavation of two pits containing more than one ton of wealth in the form of elephant tusks and artifacts of bronze, gold, jade, and stone. They were accidentally discovered by workers from a local brickyard who were digging clay to make bricks. These pits lie inside the city's south wall—although when they were excavated, in the summer of 1986, the layout of the settlement was still far from clear. During my visits to the site beginning in 1988 and through discussions with the archaeologists working there and other experts, I collected information about these finds. But their implications did not become completely apparent until 1998, with the publication of the formal ex-

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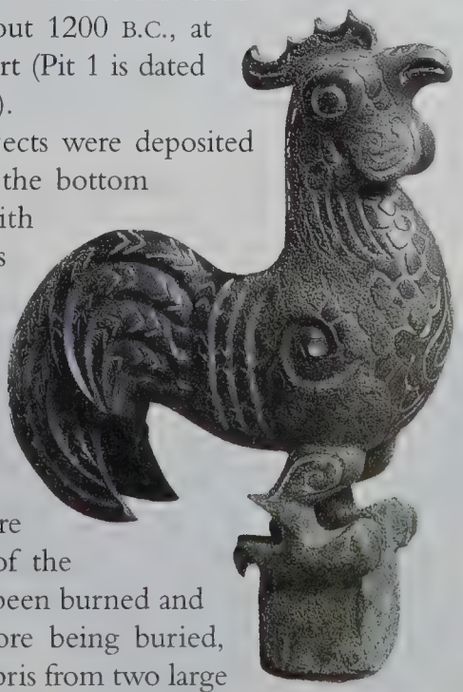
cavation report by the team led by Chen De'an, Sanxingdui field station director of the Sichuan Provincial Institute of Archaeology.

The bronze artifacts include fifty or so life-size heads, a life-size standing figure, and more than twenty masks. A few of these are partly covered in gold, a material rarely used elsewhere in China at this time. The countenances range from human to somewhat animal-like to simply weird; most are done in a unique style, with sharply cut, striking features and exaggerated eyes. Equally unprecedented finds are several bronze trees (distinct from money trees, artifacts found in second-century A.D. tombs in Sichuan and other provinces of western China), the tallest one ornamented with birds, flowers, pendants, and a dragon. The excavations have also yielded a small number of conventional bronze vessels that resemble those from other regions and enable archaeologists to determine that both pits were created in about 1200 B.C., at most several decades apart (Pit 1 is dated slightly earlier than Pit 2).

More than thirteen feet high, an ornamented bronze tree, left, was found in pieces and later partially restored. Below: The rooster from Pit 2 is the most realistic image found at the site.



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These and other objects were deposited in layers. For example, the bottom of Pit 2 was lined with pieces of the bronze trees and with small bronzes, cowrie shells, daggers, and other implements of jade and stone. The middle layer consisted of the larger bronzes, while elephant tusks were strewn on top. Much of the material in the pits had been burned and deliberately broken before being buried, suggesting that it was debris from two large

The ancient city was one of China's largest.

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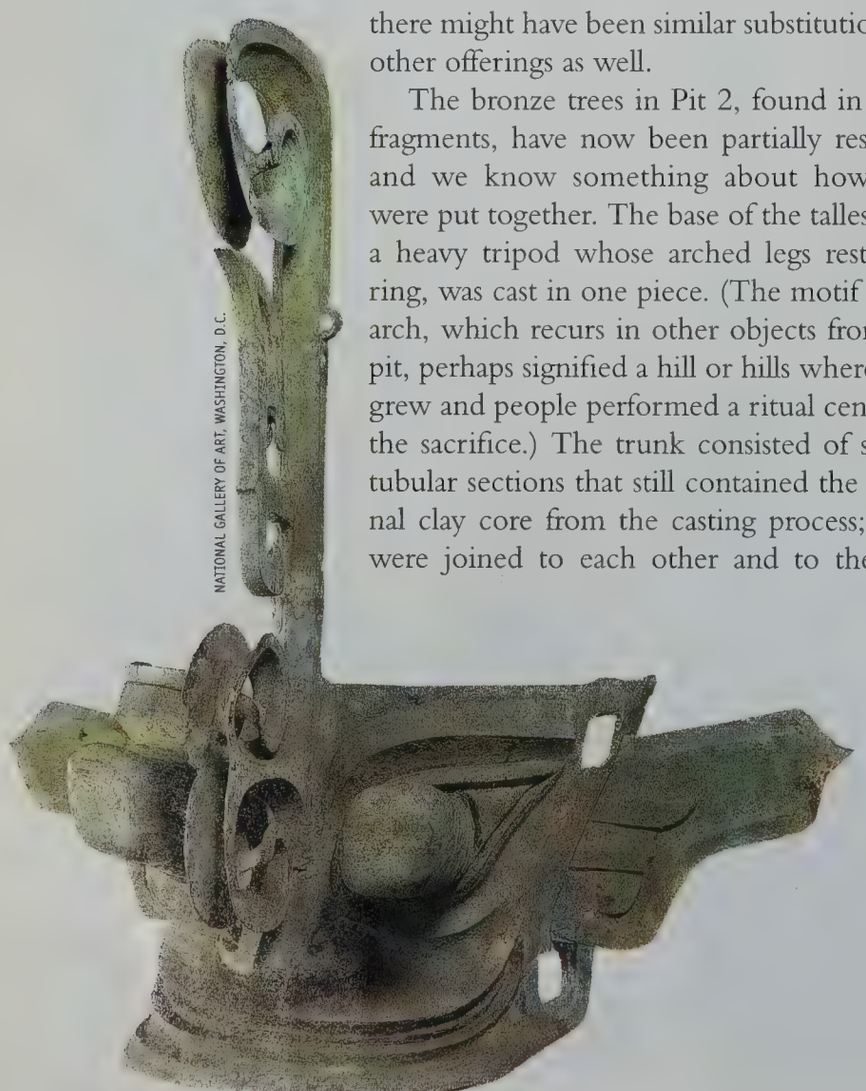
Below: A bronze mask's telescopic pupils and floppy ears—and the fantastic spiraling excrescence above its nose—suggest a creature with acute sensory powers.

sacrifices. Perhaps burning and breaking were ways of "killing" symbolic objects—items made specifically for ceremonial rituals or for sacrifices—so that they could succeed in making the passage from this world to some supernatural realm (the bronze daggers, for instance, are too flimsy to have been of practical use).

Pit 1, the earlier pit, contained many animal bones (mostly pig, sheep, cattle, and buffalo) as well as wood ash and bamboo ash. Pit 2 held more conspicuous testaments to wealth, such as bronze heads, masks, human figures, trees, birds, and even models of what might be temples or altars. Differences between the contents of the two pits might reflect an increase in the city's wealth, the growth of its bronze and jade industries, or changes in the ritual procedures themselves. Possibly the bronze trees sacrificed in the later pit were a replacement for actual trees sacrificed in the earlier one, and there might have been similar substitutions for other offerings as well.

The bronze trees in Pit 2, found in many fragments, have now been partially restored, and we know something about how they were put together. The base of the tallest tree, a heavy tripod whose arched legs rest on a ring, was cast in one piece. (The motif of the arch, which recurs in other objects from this pit, perhaps signified a hill or hills where trees grew and people performed a ritual central to the sacrifice.) The trunk consisted of several tubular sections that still contained the original clay core from the casting process; these were joined to each other and to the base with separate pours of metal. The same technique was used to assemble nine curving, bifurcated branches, each with a dozen or so separate components. The tips of the branches end in small sprigs that suggest leaves and fruits, and on these perch small birds. A dragon figure occupies one side of the tree, its forequarters resting on the base and its undulating, ropelike body (part of which is now missing) extending upward.



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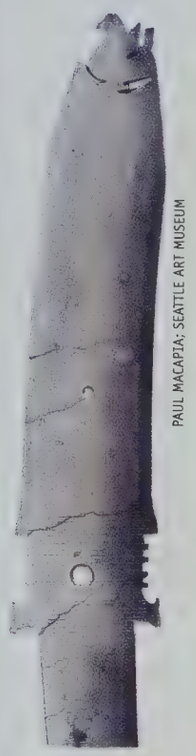
Sanxingdui's human figures and masks constitute the earliest significant collection of such imagery anywhere in China. The life-size figure, which stands on a three-foot-high pedestal, has thick arms that end in oversize hands evidently de-



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Left: Among the outsize artifacts in Pit 2 was a bronze mask nearly four feet wide. A marble *ge* blade, above, was ornamented at its tip with the incised figure of a bird.

signed to hold some object (now missing), such as an elephant tusk. The details of sumptuous clothing, including a feathered headdress, are carefully modeled, while the feet are depicted as bare. The facial features, now cloaked in the same green patina as the rest of the figure, may have originally been enlivened by colors: black for the eyebrows, pupils, and hair; red for the lips, nostrils, and ear hollows. Traces of such highlights survive on other heads and smaller figures from this site.

Most of the representations of human heads are made on the same scale as this complete figure and are given similar facial features; their necks end in a correspondingly V-shaped neckline. Possibly the heads were originally mounted on posts serving as rudimentary "bodies," which may have been concealed by rough approximations of garments or even dressed in real silk robes. A gathering of such figures, with their painted faces and their feathered headdresses, would have been an impressive sight.

Traces of coloring survive on some of the bronze masks as well. These come in various sizes, and the holes in their sides suggest that they could have been attached to posts or buildings. Many appear human, but the largest three, ranging from thirty to fifty-four inches wide, have animal-like ears and monstrously protruding pupils.

In nearby Jinsha, archaeologists have recently found new deposits.

Whatever the exact nature of the offering ritual, it was quite different from those performed during the same period at Anyang, the capital of the Shang rulers. There we find pits containing a number of human skeletons interred together, with few or no burial goods (oracle-bone inscriptions found elsewhere in Anyang mention sacrifices of several hundred human victims). The skulls are often either missing or found buried without bodies, indicating beheading; in some cases there are signs of struggle, suggesting that some victims were buried alive. Since oracle-bone inscriptions from Anyang often mention battles with enemy states and the taking of prisoners who were then sacrificed, archaeologists conclude that these skeletons are probably those of war captives. The paucity of grave goods suggests that whoever the victims were, they were people of low social standing.

Large animals were also sacrificed at Anyang, but the offerings there seldom included bronzes or jades—artifacts that were abundant in Sanxingdui. The only known sculptural images of men and gods are a few tiny jade figurines, while the bronzes are mostly elaborately ornamented ritual vessels. Considering the practice of human sacrifice at Anyang, one can speculate that the bronze heads at Sanxingdui might, in some sense, have been a substitute for live victims. Judging by their rich costumes, however, the Sanxingdui images were not of war captives or an underclass. Perhaps the offerings represented self-sacrifice by the local elite.

While these two societies differed fundamentally in religious and artistic practices and were separated by mountain barriers, they nevertheless flourished within a common sphere of cultural interaction and trade. Cowrie shells—valued items that probably came from the Indian Ocean—appear in large quantities at both Anyang and Sanxingdui. The style of certain carved jade objects, such as blades, is remarkably similar. The bronzes usually differ in style but were cast at both sites by means of ceramic molds fashioned in multiple sections. In addition, the bronze alloy itself includes the same unusual lead isotope. Lead mines in Yunnan Province, south of Sichuan, most likely supplied the foundries in both regions.

Although the two sacrificial pits remain the most dramatic finds, fieldwork continues at Sanxingdui. And to my happy surprise, while I was visiting the site last February, news broke that a new site—clearly related to Sanxingdui—had just been found about twenty-five miles to the southwest, in the village of Jinsha, outside Chengdu. A bulldozer had hit a deposit of bronzes, jades, and a few gold items; many of them are similar to those from Sanxingdui. More than a thousand objects have been salvaged so far, though no large sculptures like those at Sanxingdui have emerged.

Along with other recent finds in the middle Yangtze River Valley—such as the tomb of Xin'gan in Jiangxi Province (dating from about 1200 B.C. and discovered in 1989) and the unique large bronze bells found in Hunan Province (dated 1200–1000 B.C. and excavated over the past few decades)—the discoveries from Sanxingdui and Jinsha have begun to decisively change the picture of a Shang empire surrounded by less civilized societies. After nearly a century of archaeological investigations, we can discern a broader panorama of Bronze Age China, with highly developed cultures not only in the north but also in the south. □

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Using gold foil, below, an artist fashioned the rounded ears, lithe body, clawed feet, and stripes of a tiger. Opposite page: The ceremonial headgear of this sixteen-inch-tall bronze figure represents the head of a winged animal.

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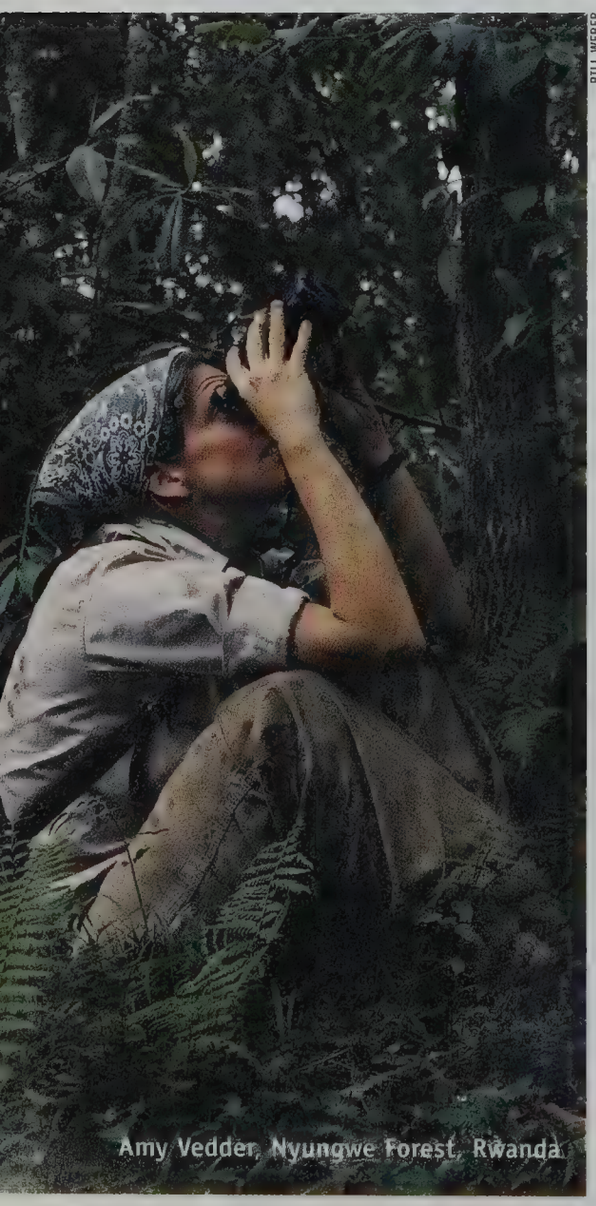
REVIEW

Field Trials

Naturalists have a bent for writing intriguing memoirs. This year has seen a bumper crop.

By Steven N. Austad

During a particularly foul time in the bush—I'm not sure whether it was while I lay immobilized on a moldering sleeping bag because of a foot so swollen it looked like a lumpy red soccer ball or when I discovered that the pungent peanuts in the chicken casserole I had so lovingly prepared were really hundreds of overcooked beetles—I began to giggle a little deliriously at the thought that someday all this might sound like a whopping fine escapade. Field biology is, after all, nine parts tedium and trouble to one part insight and adventure. The accumulated evidence of these four field memoirs, each in its own way a gripping read, suggests that I was probably having a whopping fine escapade after all.



BILL WEBER

Amy Vedder, Nyungwe Forest, Rwanda

The most traditionally autobiographical book of the lot—and the only one in which scientific discovery plays a major role—is *Captivating Life.* John Avise pioneered the use of molecular biological techniques to address key questions of evolution and behavior: whether a regional particularity in bird plumage really deserves species status, whether sea turtles return year after year to the beach where they were born. I remember quite well that in my graduate student days we derisively referred to his ilk as cell smashers and gel jockeys, who, instead of laboring to observe animals week upon week with poised notebook, simply showed up one day, took a few snips of tissue, and disappeared back into the laboratory. But they were the ones getting the best answers to the big questions—something for which I am just now beginning to forgive them.

Captivating Life: A Naturalist in the Age of Genetics, *by John C. Avise (Smithsonian Institution Press, 2001; $24.95)*

Beyond the Last Village: A Journey of Discovery in Asia's Forbidden Wilderness, *by Alan Rabinowitz (Island Press, 2001; $25)*

In the Kingdom of Gorillas: Fragile Species in a Dangerous Land, *by Bill Weber and Amy Vedder (Simon and Schuster, 2001; $27.50)*

A Primate's Memoir: A Neuroscientist's Unconventional Life Among the Baboons, *by Robert M. Sapolsky (Scribner, 2001; $25)*

Beyond the Last Village is ostensibly about working to set up a conservation program in Myanmar (formerly Burma) but is in reality a highly personal account of Alan Rabinowitz's love affair with wild places and the people and animals that live there. Dominating the story is a trek into the Himalaya of northernmost Myanmar, where no Westerner has ventured for years and where exotic mammals with exotic names like muntjac, goral, serow, and takin still haunt the forest, one step ahead of local hunters. Rabinowitz hoped to find remaining pockets of additional charismatic fauna—elephants, tigers, and rhinoceroses—and to set up a biological reserve to protect them, but he soon learned that these large mammals had disappeared.

According to this finely observed account, he learned most about the animals by querying hunters and listening intently to what they had to say. This gift for listening led him to discover that the local economy is based largely on salt. The local people don't really need to hunt wildlife, because their gardens and livestock provide sufficient food. But salt, which both humans and livestock need to survive, is nonexistent in the area, so traders bring salt from China across mountain passes and exchange it for the organs of wild animals, used in traditional medicine. This knowledge allowed Rabinowitz to work out a strategy whereby he ensured regular supplies of salt and the people could stop hunting (see "The Price of Salt," September 2000).

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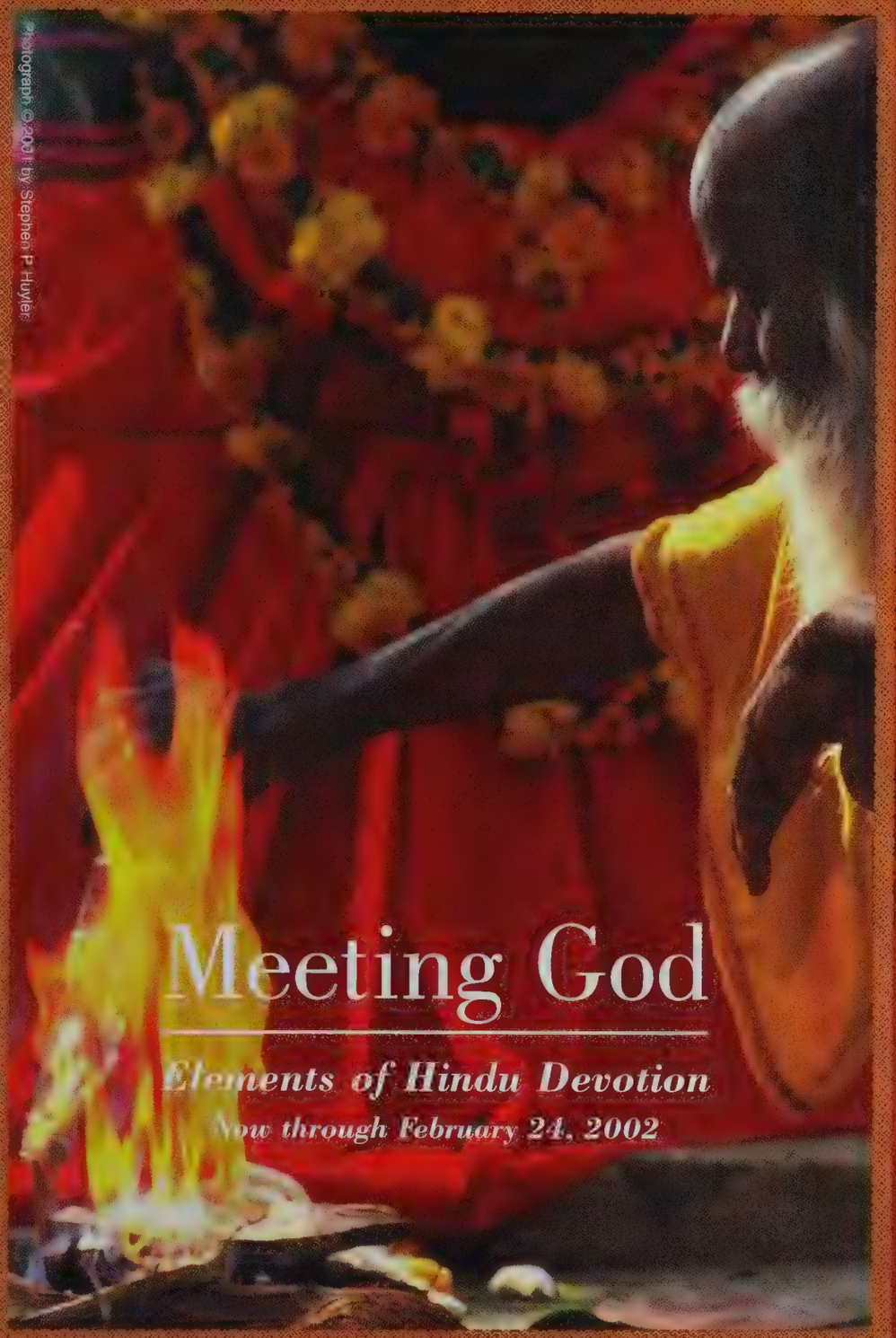

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For me, the most haunting accounts here are about the people: government officials whose personal quirks can make or break his project; the Taron "pygmies," all but extinct because of persecution, inbreeding, and despair; a mother so desperate to save her ill baby

that she gives up the infant to Rabinowitz's Burmese colleague.

Bill Weber and Amy Vedder's *In the Kingdom of Gorillas* is an account of their work with mountain gorillas in Rwanda. In 1973, en route to their Peace Corps posting in eastern Congo, the newly married couple was detained in Uganda by troops under orders from the bloodthirsty tyrant Idi Amin. Despite this inauspicious beginning, they developed an appreciation for the people and cultures of Africa that led eventually to their decade-long involvement in a Wildlife Conservation Society project on gorillas in the subalpine forests of neighboring Rwanda.

At first, the most difficult 500-pound gorilla they had to contend with was Dian Fossey, international media star, who loved the gorillas and had suffered mightily to study them. By the time Weber and Vedder met her, she had dissolved into alcoholism and paranoia to such a degree that she was harming gorilla preservation efforts more than helping them. Offering Weber a gun as he set off to census the remaining gorillas for the first time, Fossey instructed him, "If you see anyone in the park, shoot them." A previous worker had taken her at her word, shooting and paralyzing a suspected poacher, which led his friends and family to kill five gorillas in retaliation.

Later, Weber and Vedder came up against AIDS and unparalleled ethnic violence, which devastated their project, their Rwandan friends, and the region itself. They provide a vivid portrait of a land desperately trying to put itself back together. The gorillas survive.

Mountain gorillas also fascinated Robert Sapolsky, but, as he writes in *A Primate's Memoir,* he joined a baboon troop in Kenya's Serengeti Plain instead. The year was 1978, when I, too, made my first trip to Africa and was fleeced on the streets of Nairobi by probably some of the same con artists (with their eye for American pigeons) whom he describes. Rarely have I encountered a scientist who became so attached to his study animals, giving them biblical names and roles and fleshing out descriptions of their individual personalities the way he might his childhood chums. Which makes it all the more horrifying when, after twenty years of increasingly intimate acquaintance, his baboon friends begin dying, one after another, for preventable reasons that he can do nothing about. A tale of deep humanity played out between two primate species, the book resonates with humor but also with the outsize emotions: sorrow and fear and joy.

Steven N. Austad is a professor of zoology at the University of Idaho and the author of Why We Age: What Science Is Discovering About the Body's Journey Through Life *(John Wiley and Sons, 1997).*

nature.net

Natural Borders

By Robert Anderson

I love maps, especially maps that convey information about our world in a novel way. I was therefore happy to find at Wild World (www.nationalgeographic.com/wildworld) a pair of interactive maps created by the National Geographic Society in collaboration with the World Wildlife Fund.

The first map, "Global 200," shows 200 regions (on land and in the seas) for which conservation efforts are crucial because they are home to the richest, rarest, and most endangered biological communities. I was surprised to learn that Los Angeles, where I live, is right in the middle of one of these special places—47,000 square miles of California chaparral and woodlands. This relatively small and highly threatened area is one of just five spots on Earth with a Mediterranean climate. Together, these regions harbor 20 percent of the world's plant species. Rainforests aren't the only places in critical need of help.

The second interactive map, "Terrestrial Ecoregions of the World," shows the world's landmass divided into ecoregions—867 of them—instead of into the usual political demarcations. These entities are distinguished by shared ecological features of climate and of plant and animal communities. You can quickly find yours by typing in your zip code. My ecoregion (a subdivision of the area described above) is California coastal sage and chaparral, or NA 1201. When I clicked on it, I got an overview of the flora and fauna, and I learned that the protected patches of my ecoregion are generally too small to conserve intact natural communities. More information was available via a link to the World Wildlife Fund's scientific report.

Robert Anderson is a freelance science writer living in Los Angeles.

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BOOKSHELF

Aquagenesis: The Origin and Evolution of Life in the Sea, *by Richard Ellis (Viking/Penguin, 2001; $25.95)*
With a sense of exuberance and wonder, marine artist and writer Richard Ellis investigates the evolution of sea life, especially land animals that have returned to an aquatic existence—such as whales, seals, manatees, and penguins. He manages the daunting task of compressing 300 million years of evolution into a very readable book.

The Evolution Explosion: How Humans Cause Rapid Evolutionary Change, *by Stephen R. Palumbi (W. W. Norton, 2001; $24.95)*
Whether in TB's resistance to antibiotics or the diamondback moth's immunity to the deadly pesticide known as Bt toxin, the force of human-driven natural selection is abundantly evident. Harvard biologist Palumbi looks at our species' impact on evolution and the ways we ourselves continue to evolve.

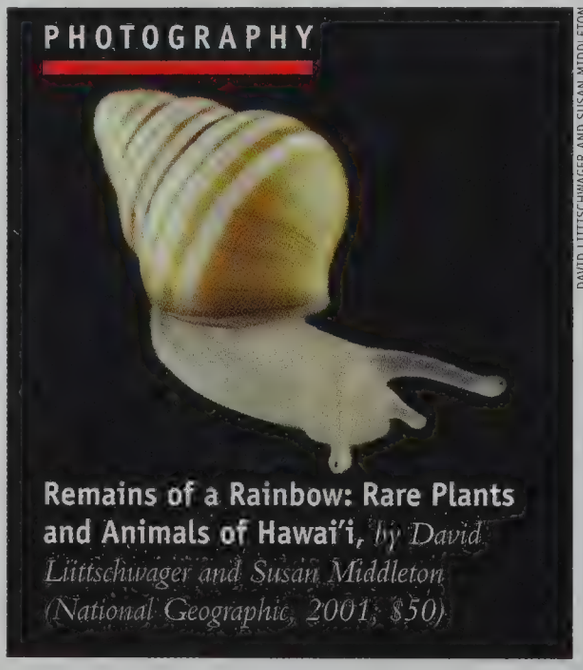
The Botany of Desire: A Plant's-Eye View of the World, *by Michael Pollan (Random House, 2001; $24.95)*
Linking the destinies of apple, tulip, potato, and cannabis species to our own, this entertaining and informed book celebrates how plants, animals, and microbes respond with "so many different and unexpected answers to the deep pulse of their genes and the wide press of their surroundings."

Hubbert's Peak: The Impending World Oil Shortage, *by Kenneth S. Deffeyes (Princeton University Press, 2001; $24.95)*
Geologist M. King Hubbert proved correct in his 1956 prediction that U.S. oil production would peak in the early 1970s. Now analysts have applied Hubbert's method to global oil output. They estimate that between 2004 and 2008, supplies will begin a permanent decline. This is a sobering look at fossil fuels and alternative energy sources.

World Atlas of Coral Reefs, *by Mark D. Spalding, Corinna Ravilious, and Edmund P. Green (University of California Press, 2001; $45)*
Enormous, spectacular, and dense with overwhelmingly diverse life, the planet's tropical reefs are visible even from space. This exhaustive, area-by-area assessment of an increasingly threatened ecosystem includes text, photographs, tables, and splendid, up-to-date maps.

Great Waters: An Atlantic Passage, *by Deborah Cramer (W. W. Norton, 2001; $27.95)*
The origins, organisms, and movements of the vast Atlantic Ocean (which covers 32 million square miles and reaches depths of 12,000 feet) are illuminated by an author who spent a decade researching the scientific literature and many weeks aboard a research vessel visiting "the rough, chilly Gulf of Maine" as well as "the calm, weedy Sargasso."

PHOTOGRAPHY



DAVID LITTSCHWAGER AND SUSAN MIDDLETON

Remains of a Rainbow: Rare Plants and Animals of Hawai'i, *by David Littschwager and Susan Middleton (National Geographic, 2001; $50)*

Life Script: How the Human Genome Discoveries Will Transform Medicine and Enhance Your Health, *by Nicholas Wade (Simon & Schuster, 2001; $24)*
By decoding the 3 billion DNA "letters" spelling out all the genes that create and maintain the human body, the Human Genome Project will open up new ways to pinpoint the genetic causes of disease, permit individualized diagnostics, and lead to new treatments.

Platypus: The Extraordinary Story of How a Curious Creature Baffled the World, *by Ann Moyal (Smithsonian Institution Press, 2001; $21.95)*
In 1799 a strange Australian specimen, "a small amphibious animal of the mole kind," arrived at the Royal Society of London. "Neither fish nor fowl, bird or reptile," this monotreme puzzled scientists for a century before its biology—especially its antediluvian sensory system—was understood.

This Cold Heaven: Seven Seasons in Greenland, *by Gretel Ehrlich (Pantheon Books, 2001; $27.50)*
Writer and poet Ehrlich traveled to the "world's largest island" in 1993 and fell in love with it. Her heroes, the Inuit people (who reached Greenland thousands of years ago), have created a "cold-adapted, boreal culture, a single entity [that] stretches 6,000 miles across ice caps, pressure ice, barren lands, rivers, mountains, fjords, and frozen oceans."

The Tapir's Morning Bath: Mysteries of the Tropical Rain Forest and the Scientists Who Are Trying to Solve Them, *by Elizabeth Royte (Houghton Mifflin, 2001; $25)*
Barro Colorado Island is a living ecological laboratory located in the middle of Gatun Lake (part of the Panama Canal system). It has been administered by the Smithsonian Institution since 1923. As the author accompanies researchers counting seedlings or sorting insects, she muses on the evolutionary and ecological questions raised by the fieldwork.

The books mentioned are usually available in the Museum Shop, (212) 769-5150, or via the Museum's Web site, www.amnh.org.

National Collector's Mint announces a limited release of the ...

2001 U.S. GOV'T "AMERICA UNITED" SILVER EAGLE DOLLAR

To benefit the victims and families of the September 11, 2001 attack on America

WASHINGTON, D.C., Corp. ID Center, Thursday, 8:55 AM - Today history is being made. America is uniting as it has not done since the Japanese attacked Pearl Harbor 60 years ago.

In response to the terrorist attack on the World Trade Center and the Pentagon the morning of September 11, 2001, thousands of men and women came forward to help rescue efforts. Hundreds of businesses volunteered their services.

In that spirit, the National Collector's Mint is releasing the "America United" Silver Eagle Dollar, a Brilliant Uncirculated 2001 U.S. Government Silver Eagle, with the Twin Towers of the World Trade Center standing proudly in full color across its obverse as the Stars and Stripes flies above them.

For each "America United" Silver Eagle Dollar purchased, National Collector's Mint is making a $7.00 donation to the United Way's September 11th Fund, providing immediate and long-term aid to victims and their families. We expect to lose money. But, after their sacrifices, helping victims and their families is more important. In fact, it's the only thing that's important.

Help America Rise Again

The "America United" Silver Eagle Dollar is a statement of your commitment to support America's struggle against the shadowy enemy. Each coin is a legal tender Silver Eagle Dollar, the biggest, heaviest and purest silver coin ever minted by the U.S. Government. The full-color image of the World Trade Center and the American flag appears across its obverse, with the never-to-be-forgotten date of the attack, September 11, 2001. Beneath this brilliant image, Lady Liberty strides toward us out of the dawn. On the reverse is the great heraldic eagle. Emblazoned across it stands the American flag in full-color, and the legend, "God Bless America."

Advance Discount Price

The issue price of your "America United" Silver Eagle Dollar was originally set at $49.00. But, in order to raise funds as quickly as possible, and to put as many of these precious coins into the hands of Americans who want to memorialize this tragedy, and proclaim our unity, the issue price of this pure silver masterpiece has been cut to just $29.95.

Each solid silver "America United" Silver Eagle Dollar comes with an individually numbered Certificate of Authenticity. Earliest orders receive the lowest registration numbers. A velvet presentation case is available for $3.50.

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Composition	Full Color on .999 Pure Silver
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Diameter	40.6 mm
Condition	Brilliant Uncirculated
Series	EE
Release Limit	75,000 Worldwide
Registration	By number in ascending order

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CELESTIAL EVENTS

Outta Sight

Once in a while, Jupiter's moons take a walk.

By Richard Panek

An artist's vision of Jupiter hovering above the ice spires of Callisto, one of the planet's four Galilean moons. The three other moons are to Jupiter's right.

If Galileo had first looked at Jupiter through a spyglass powerful enough to discern the planet's moons a few evenings earlier or later than January 7, 1610, what he might have seen was this: Jupiter. *Just* Jupiter.

Instead, what he famously observed on the night of the 7th was Jupiter accompanied by a distinctive arrangement of "stars"—three pinpoints of light in a curiously straight line, two on one side of the planet, one on the other. Galileo looked at Jupiter again the following evening; this time he found the three stars all to one side of Jupiter. At first he suspected that the planet had changed position relative to the stars, even though such repositioning would have contradicted standard predictions for Jupiter's trajectory. Over the following week, however, Galileo not only located a fourth star accompanying Jupiter but also began to suspect that what was jumping around wasn't Jupiter; it was the mysterious "stars" themselves—the four bodies that today we know as the Galilean moons.

Of all the revolutionary discoveries Galileo made in his first months of using a telescope to study the night sky—including mountains on our own Moon and multitudes of stars invisible to the naked eye—it was this observation that prompted him to rush these findings into print. The presence of moons orbiting Jupiter didn't decisively validate Copernicus's 1543 hypothesis that the planets go around the Sun (Galileo's observation of the phases of Venus would soon do that; see "Celestial Events," June 1999). But it did demonstrate that Earth, dragging along its own Moon, isn't the only body in the universe that serves as a center of motion.

The Galilean moons aren't always visible to us. Each disappears from view when it passes behind (is occulted by) the planet. And when one of them passes in front of (transits) Jupiter, the two bodies can't be distinguished from each other with even quite sophisticated amateur instruments. Certainly Galileo's primitive telescope would have been inadequate to the task.

The occultations and transits of Io, the Galilean moon closest to Jupiter, begin about every twenty-one hours and last just over two hours. Callisto, the moon farthest from Jupiter, disappears, or nearly so, every eight and a third days for about four hours—"nearly so" because from our perspective, its orbit often takes it just above or below Jupiter rather than across it. Between these two extremes falls Europa, which vanishes every forty-two hours, and Ganymede, every three and a half days. The simultaneous disappearance of two Galilean moons isn't all that unusual. The disappearance of three at the same time, however, is.

Unusual but not irregular. Every six months or so, the three innermost moons vanish from sight simultaneously for a few minutes at a time. These disappearances can occur four, five, or more times at three-and-a-half-day intervals (the length of time between an occultation and a transit of Ganymede, the outermost of these three moons).

By a quirk of fate, Galileo began his historic observations of Jupiter on January 7, 1610, smack in the middle of one such spate of disappearances. Five evenings earlier, for an observer who happened to be where Galileo was (in Padua) at the very time that Galileo would soon begin his daily studies of the planet through his optic

tube ("the first hour of night"), three of Jupiter's moons would have been out of sight. The fourth and farthest, Callisto, would have been distant enough in its orbit that Galileo might very well have overlooked it or, at any rate, failed to associate it with the planet. This precise celestial arrangement happened to repeat itself on January 6, though not at a time of day when Jupiter would have been above the horizon for an observer in Padua. On January 9, when the same circumstances recurred, Galileo in fact attempted to observe Jupiter—but cloud cover obscured his view.

Another such spate of disappearances is currently coming to an end. For an observer in New York, the moons Europa, Ganymede, and Io disappeared at about 5:00 A.M. on October 18 and remained out of sight right through sunrise. The same three moons disappeared again on October 21, but Jupiter was below the U.S. horizon at the time. On November 8, three Galilean moons will vanish once more, with Callisto—usually the distant straggler—among the missing. Ganymede will be the odd moon out, though by a distance from Jupiter of less than fifty arc seconds, or about 1/37 the width of our full Moon. So for virtually any amateur observer, the four Galilean moons will pass temporarily out of sight that day, beginning about 16:30 Universal time.

Not, alas, in New York, where the disappearance will occur at 11:30 A.M. And not in Padua, where Jupiter will be below the horizon. But if you happen to find yourself in Hawaii in the predawn hours of November 8, you'll be able to witness a sight that even Galileo never got to see, although it was one he thoroughly expected to find when he looked through his primitive telescope on January 7, 1610: *just* Jupiter.

Richard Panek's new book, The Invisible Century: Einstein, Freud, and Our Search for Hidden Universes, *will be published next year by Viking.*

THE SKY IN NOVEMBER

By Joe Rao

Mercury descends from its excellent morning viewing position of late October. It gradually drops lower into the bright morning twilight, hovering less than 1° from Venus through November 7. Also close by is the first-magnitude star Spica, a blue gem. During the first five days of November, Venus, Mercury, and Spica form a trio. Mercury is visible 2° to the lower left of Venus on the 11th, increasing to 4° by the 17th. Mercury slowly brightens during this interval, reaching magnitude -0.9. In the third week of November, the planet drops deep into the morning twilight and is lost in the glare of the Sun.

Venus rises almost due east about one and a half hours before sunup on the 1st. Spica is close to Venus the first week of November; Mercury lingers nearby through midmonth. On the 3rd, Venus passes 3.5° north of Spica. A thin crescent Moon is visible above Venus and to the lower left of Spica on the morning of the 13th. Venus sinks deeper into the dawn twilight throughout the month.

Mars, in Capricornus throughout November, can be found in the southwestern sky at dusk, setting just before 10:30 P.M. local standard time (LST). It starts the month at magnitude +0.1 and dims to +0.4 by the end.

Jupiter glimmers above the eastern horizon by 9:00 P.M. LST at the beginning of November and by 7:00 P.M. LST at month's end, reaching its highest point in the sky during the predawn hours. Late on the night of November 5–6, the Moon passes 1.5° north of Jupiter.

Saturn dominates the constellation Taurus this month. It rises about two hours after sunset early in November but only fifteen minutes after sundown by the 30th. On the evening of November 3 it hovers close to the Moon. On the 30th the ringed planet is occulted by the full Moon for much of North America; it disappears at roughly 7:30 P.M. LST in the East and 5:00 P.M. LST in the far Southwest.

The Moon is full twice in November for those in the eastern time zone—on the 1st at 12:41 A.M. and on the 30th at 3:49 P.M. Last quarter comes on the 8th at 7:21 A.M. The Moon is new on the 15th at 1:40 A.M., and first quarter comes on the 22nd at 6:21 P.M.

The Leonid meteor shower should reach a peak over North America on the morning of November 18 between 5:00 and 5:30 A.M. Try to get an unobstructed view of the sky far from city lights. The meteors will be radiating from the sickle of Leo. Keep alert for brilliant fireballs or exploding meteors. This year's shower may include a brief outburst of up to 2,500 meteors per hour. If the weather cooperates, you might see more "shooting stars" than you ever have before. Eight hours later—when it's daytime in the Western Hemisphere—an even grander Leonid display, with possible rates of up to 15,000 per hour, is expected over eastern Asia and western Australia. To learn more about the display, go to www.hometown.aol.com/theleonids.

Unless otherwise noted, all times are given in Eastern Standard Time.

BIOMECHANICS

Sand Dune Two-Step

The need for speed may bring these lizards to their (hind) feet.

Story by Adam Summers ~ Illustration by Sally J. Bensusen

As the sun rises over the Mojave Desert, its pale yellow light casts every irregularity into stark relief. Countless pockmarks and minute tracings on the surface of the dunes provide evidence of a busy night for kangaroo rats and sidewinders—the scuffling of tiny feet, the swishing of curved bodies, and the occasional mad sprint to escape a predator. But one small patch of the Kelso Dunes in the southeastern area of the desert is strangely lacking in such sandy signs, having been blown smooth by biologists wielding gas-powered leaf blowers. These researchers are testing out their theories of lizard locomotion.

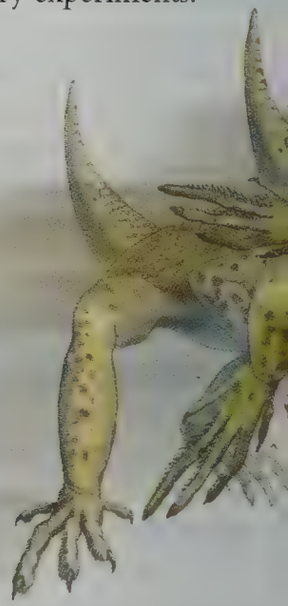
Among the most astonishing residents of the dry and apparently barren Kelso Dunes is the Mojave fringe-toed lizard *(Uma scoparia)*. This small, finely checkered lizard is active during the day, skittering across the sand in search of invertebrate prey. Occasionally it disappears in a flash as it deftly burrows into the sand. For a real show, try catching one of these lizards. It races away in a sudden burst of speed, its front end lifting off the ground like a hot rod, its forelimbs weakly pawing the air. As the four-inch-long creature dashes off at thirteen feet per second, its hind limbs windmill like the legs of a cartoon character making a fast getaway, and its long toes flare, each bearing an expanded row of scales that provide traction in the sand.

Scientists assume that being fleet of foot boosts evolutionary fitness by helping an animal avoid becoming someone's dinner for long enough to produce lots of offspring. As a result, a great deal of research has been conducted on the relationship between speed and such variables as leg length; how long feet stay in contact with the ground; and the degree to which the legs are splayed, as in lizards, or held underneath the body, as in mammals (except for the duck-billed platypus). So, using a lizard-sized treadmill and high-speed cameras, Bruce Jayne, of the University of Cincinnati, and Duncan Irschick, of Tulane University, have been gathering sprinting data for the Mojave fringe-toed lizard as well as for its close relative, the zebra-tailed lizard *(Callisaurus draconoides)*.

In the laboratory, the researchers determined the top speed of both species and also when they use two legs and when they use four. The longer-legged zebra-tailed lizard—which, like its relative, is diurnal but which inhabits a wider range of terrains, from fine sand to the hardpan of desert washes—runs much faster than the fringe-toed lizard, even on loose sand, where the researchers had expected the latter's toe cleats to be a significant advantage. And oddly, though the researchers assumed that running on two legs would be quicker than running on all four, they found that after the first few seconds of movement, when both species can run bipedally, there was little difference in speed between the two modes of locomotion. Running on two legs may facilitate quick acceleration or may simply be an unintended consequence of it.

Laboratory studies like these are useful for purposes such as understanding the mechanics of a rapid, sprawling gait or making an evolutionary comparison between species. However, Irschick and Jayne wanted to know how the lizards perform outside the contrived conditions of a biology lab. In the field, they wondered, are the animals content to creep around most of the time, sprinting only when necessary, or do they regularly dart from place to place?

To circumvent the problems of exposing high-tech electronic equipment to sand and extreme heat, Jayne and Irschick borrowed a tactic from Sherlock Holmes: they measured the footprints left by lizards and then compared the prints with data from the laboratory experiments.

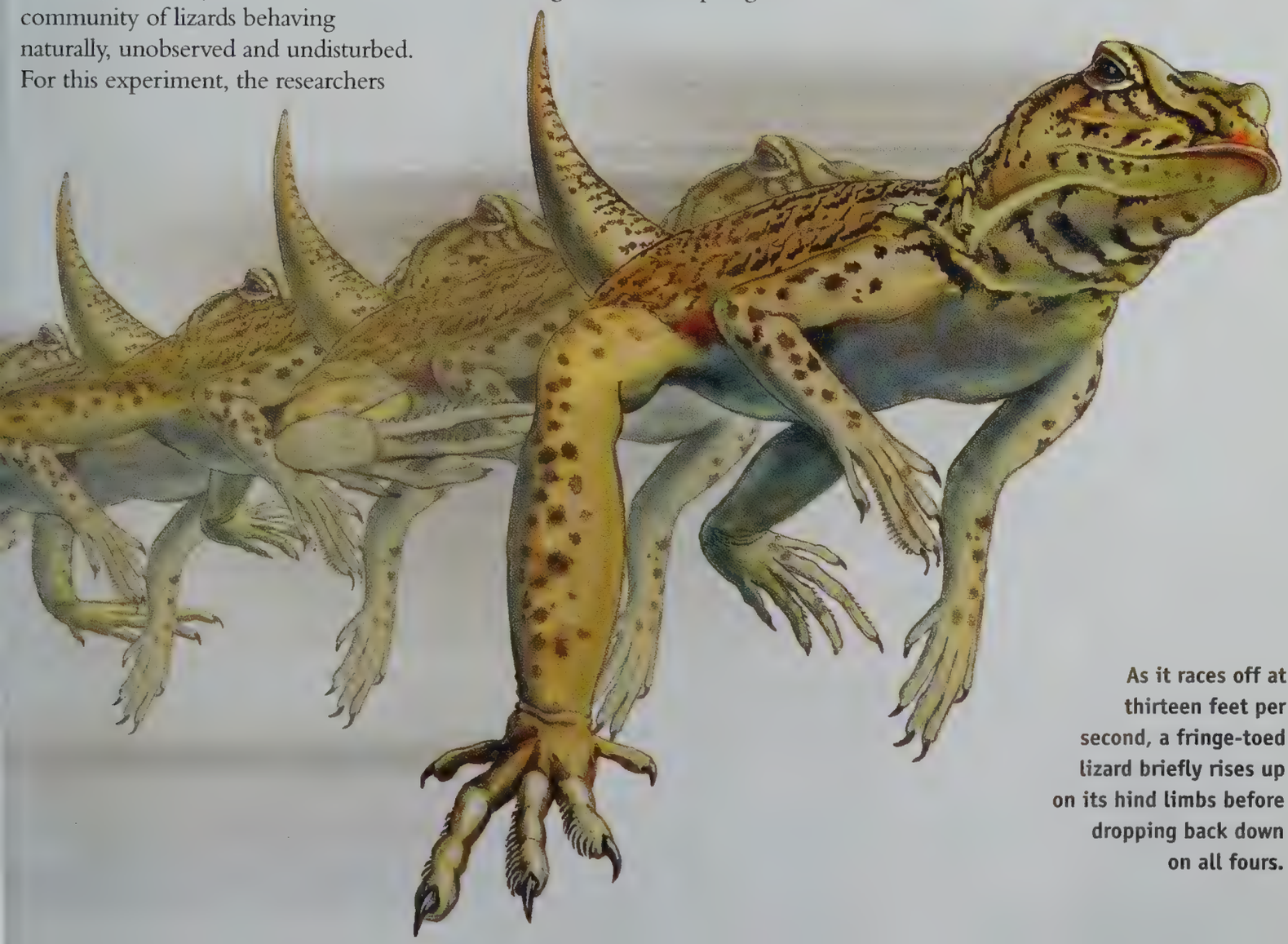


In their early experiments on the dunes, the researchers simply walked up to lizards and observed the animals as they sped off. They found that on gentle slopes, both species were just as likely to run uphill as they were to run down or across, so long as the direction was *away*. On steeper slopes, the zebra-tailed lizards tended to run across the hill, presumably because uphill would be slower and downhill more apt to result in a tumbling fall. While both species ran on two feet at first, as they did in the lab, it turned out that the fringe-toed lizard resumed quadrupedal running after just a few upright steps, while the gangly zebra-tail remained bipedal for nearly half the escape strides.

The smoothed patch on the Kelso Dunes is one of several sites in the Mojave where Jayne and Irschick have set up a more ambitious experiment so that they can study locomotion in a community of lizards behaving naturally, unobserved and undisturbed. For this experiment, the researchers deploy their leaf blowers at night and then retreat, leaving behind a blank slate ready to record the animals' movements. The lizards are active for several hours during the relative cool of morning and again in the early evening. When the sun is high, they seek cover in burrows or under vegetation. At this point the researchers, braving the heat (up to 115° F), examine the dunes to measure the lizards' tracks.

Over the course of several weeks, the research team measured more than 5,000 footfalls in more than 300 trackways. Calculating the slope of each path and the speed of the animal that made it, they found that the fringe-toed lizard moves remarkably quickly when covering longer distances. In the lab, the lizards displayed a range of speeds, but in the field they preferred just two speeds: an exhausting dash across open ground and a slow, aerobically sustainable walk when foraging near cover. Surprisingly, they rarely ran on two legs out in the Mojave when no six-foot-tall researchers were there to alarm them; the need for rapid acceleration may arise less frequently in the wild than it does on treadmills in a laboratory. In one intriguing trackway, the footfalls of a fringe-toed lizard were paralleled by the prints of a roadrunner, a lizard-eating bird. After several feet, the lizard tracks disappeared abruptly: evidence of a well-timed dive under the sand or perhaps an indication that no matter how fast the lizards are, they do not always win the race.

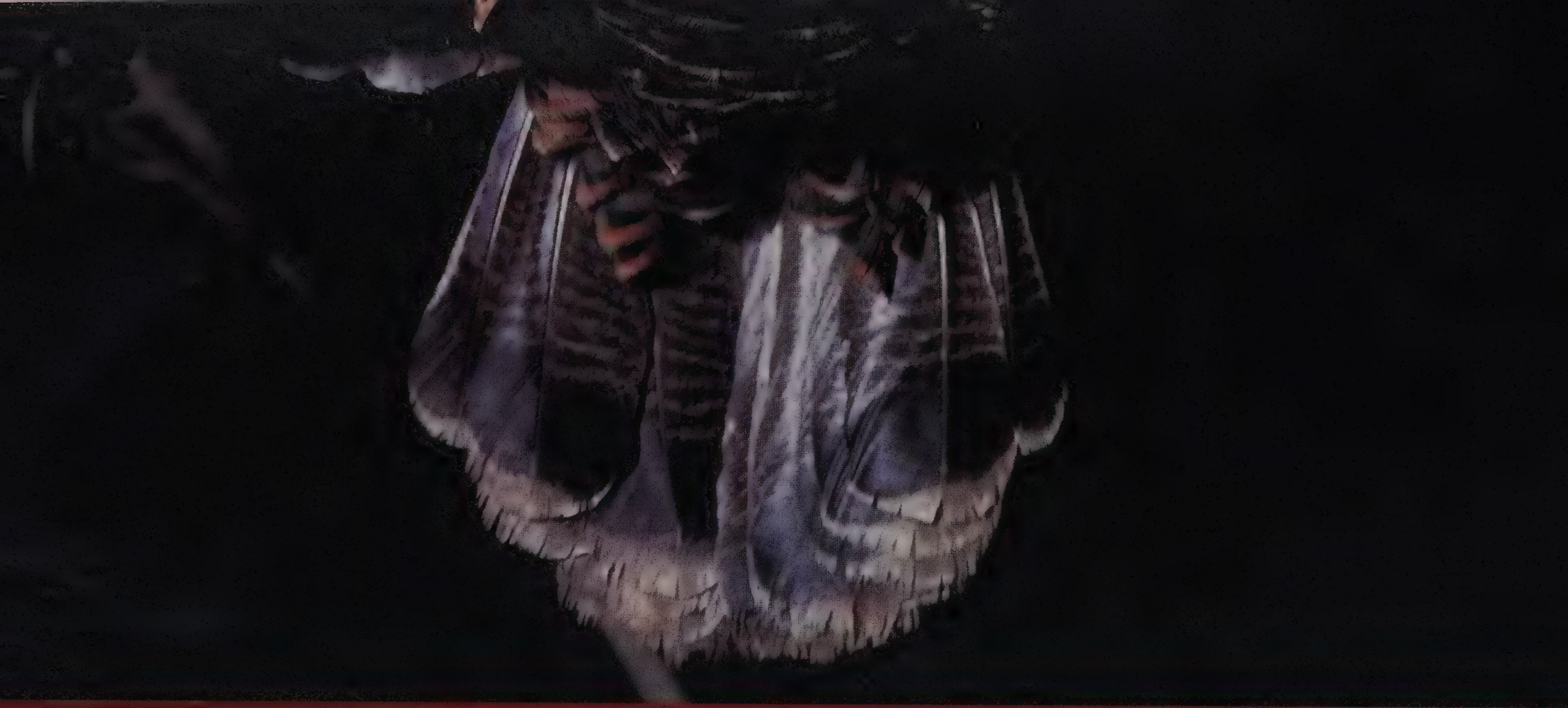
Adam Summers is an assistant professor of ecology and evolutionary biology at the University of California, Irvine (asummers@uci.edu).



As it races off at thirteen feet per second, a fringe-toed lizard briefly rises up on its hind limbs before dropping back down on all fours.

Stuffin'

Photograph by
Gary W. Griffen



By the end of the nineteenth century, North America's indigenous wild turkey had dim prospects of survival. Once so common that colonial markets sold the bird for two cents a pound, this relative of the pheasant was relentlessly hunted and its forest habitats cleared for agriculture. It seemed that only the smaller-brained, domesticated turkey, bred for centuries by Native Americans in Mexico, would survive. But as acres of farmland gradually returned to forest, the wild turkey repopulated its former range in thirty-nine states and extended its range into all other states except Alaska, thanks mainly to "capture and release" programs.

Ground-dwelling omnivores, turkeys walk miles foraging for nuts, insects, and other edibles. While hens usually travel together, toms (males) roam either in separate flocks or alone. In spring they seek out hens, enticing them with spectacular displays of gobbling, feather fluffing, and quill buzzing. Sometimes a male travels with a group of females, mating with as many as possible.

In late April or early May, hens nest on the ground, where they lay about a dozen eggs over a two-week period. After twenty-eight days, the poults hatch and immediately begin to follow their mother closely. Just before sunset each evening, the hen flies up to a tree's lower limb and calls to the poults, which fly up and scramble for places next to her, even clustering on her back or neck if they cannot crowd beneath her wings for warmth.

This brooding hen was photographed in the Tacome Range in New York State, near the Connecticut border. Although the youngsters are favored targets of owls, snakes, opossums, coyotes, and foxes, mother turkeys have been successful in rearing enough of them to ensure the triumphant comeback of the wild turkey. —*Richard Milner*

ENDPAPER

The LAST DAYS of an ASSASSIN

By Elizabeth Cator

On the midsummer morning I took it captive, the wheel bug was clinging to the stem of a swamp milkweed, its lethal beak plunged deep into the limp body of a monarch caterpillar. I picked the stem and carried it home. Since monarch caterpillars are notoriously toxic, I expected the wheel bug to die.

A wheel bug *(Arilus cristatus)* is both fearsome and comical. None of its parts match: spindly legs on a hulk of a body; a disproportionately small head; front femurs like massive biceps; a fantastic, cogwheel-like toothed semicircle erupting from its back. Years ago I found one lurking on a sumac at

Wheel bug *(Arilus cristatus)*

DAVID DENNIS; ANIMALS ANIMALS

the edge of a field. Its gray body black in the shadows, it sat motionless until I reached out a finger (an unwise move), prompting it to back slowly away. A shy, retiring insect, I thought, and was surprised to learn that it belonged to the family of assassin bugs and could have stabbed me.

My captive assassin, imprisoned in a bucket roofed with cheesecloth and set in a sheltered corner of the patio, went on feeding. Next morning I found it clinging to the underside of the cheesecloth, looking as lively as a wheel bug gets. I wondered what else it would eat and threw it a tobacco hornworm on a tomato leaf. It seemed not to notice, yet some hours later I saw that it had climbed down and was creeping toward the somnolent hornworm.

Millimeter by millimeter, with many long pauses, the wheel bug advanced. The whole time, one of its long, jointed antennae swept the air in a wide arc. The tip grazed the hornworm's head, more than an inch away. Provoking no response, the antenna tapped segment by segment along the body until, with a jerk, the hornworm began to crawl—not away but fatally forward. It was the wheel bug that then moved back, cautiously edging around to position itself directly in front of the advancing hornworm. Still the restless antenna swept and tapped. It tapped the hornworm's last segment; at once the wheel bug reared up on its two pairs of stiltlike hind legs, raised its burly forelegs beside its head, and stood like a trestle as the hornworm inched underneath. This is how the monarch must have died, in an event both random and inevitable: the grasping forelegs snapping down, the tarsal hooks sinking in, the curved needle-beak plunging, jerking up, plunging again. There was no struggle. A drop of green fluid fell to the floor of the bucket as the wheel bug began to suck up the nutritious innards of its prey.

The banquet lasted many hours; by evening, the hornworm's desiccated skin hung from the tomato leaf and the wheel bug was back on its cheesecloth ceiling.

It continued to thrive. I scattered leaf litter on the floor of the bucket and threw in another hornworm, then a squash bug, a bluebottle fly, a spiny orb weaver, a daddy longlegs, a bald-faced hornet, a wolf spider, and various unidentified larvae. Most were live, some were stunned, and a few were dead; many must have been exotic fare, but the wheel bug rejected only a yellow jacket (dead) and a stinkbug (live)—evidence, perhaps, of some gustatory standards, however low. Between meals the wheel bug hung motionless, sometimes for days, on the cheesecloth.

So it went until early November. After the frost the wheel bug retired to the leaf litter, where it lay fasting but made no attempt to burrow in and hibernate.

Then something mysterious happened. All summer I had seen no other wheel bugs, but now one appeared over the kitchen door. Slightly larger than the captive, it was some thirty feet from the bucket when I first noticed it. I never saw it in motion; from time to time I noticed that it was no longer where I had last seen it. Day by day, it made its way across the ceiling, down the wall, and eventually to the bucket's cheesecloth roof. The journey lasted two weeks.

For days neither wheel bug stirred. The captive lay on the leaves, the newcomer on the top of the cheesecloth. When I touched either one, a leg slowly lifted and then froze. One morning there was no response from either bug. With tarsi still hooked to the cheesecloth mesh, the newcomer was dead. Down on the leaves, the captive, too, had died.

Insect lives are short and surprising. My wheel bug not only survived a meal of poison caterpillar and months of imprisonment but appeared, at the end of its life, perhaps to have attracted a suitor. Or so I imagined. But for this slow and deliberate couple, time had simply run out.

English-born Elizabeth Cator is an embroiderer. She watches bugs in Hartwood, Virginia.

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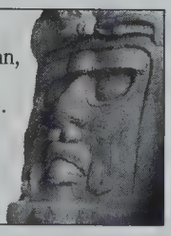

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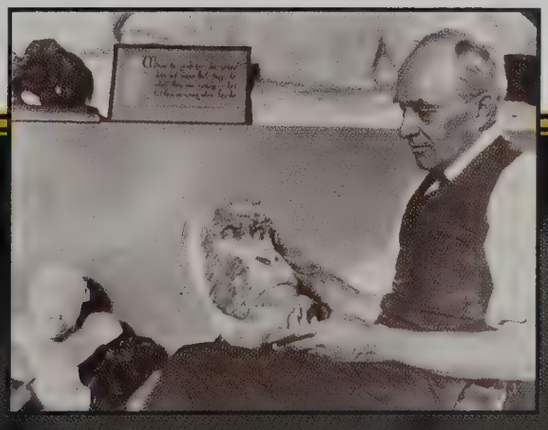

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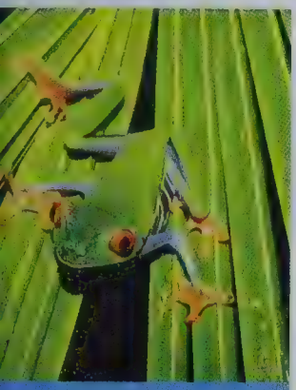
Henry David Thoreau



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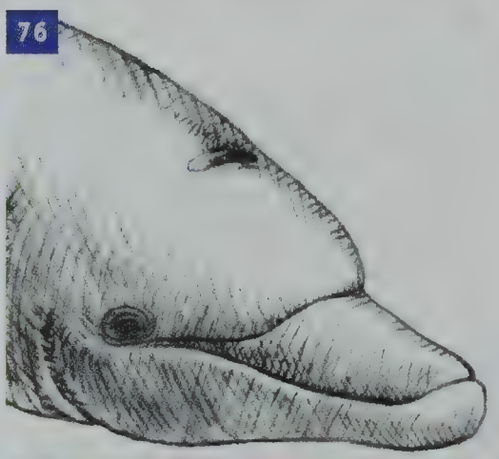

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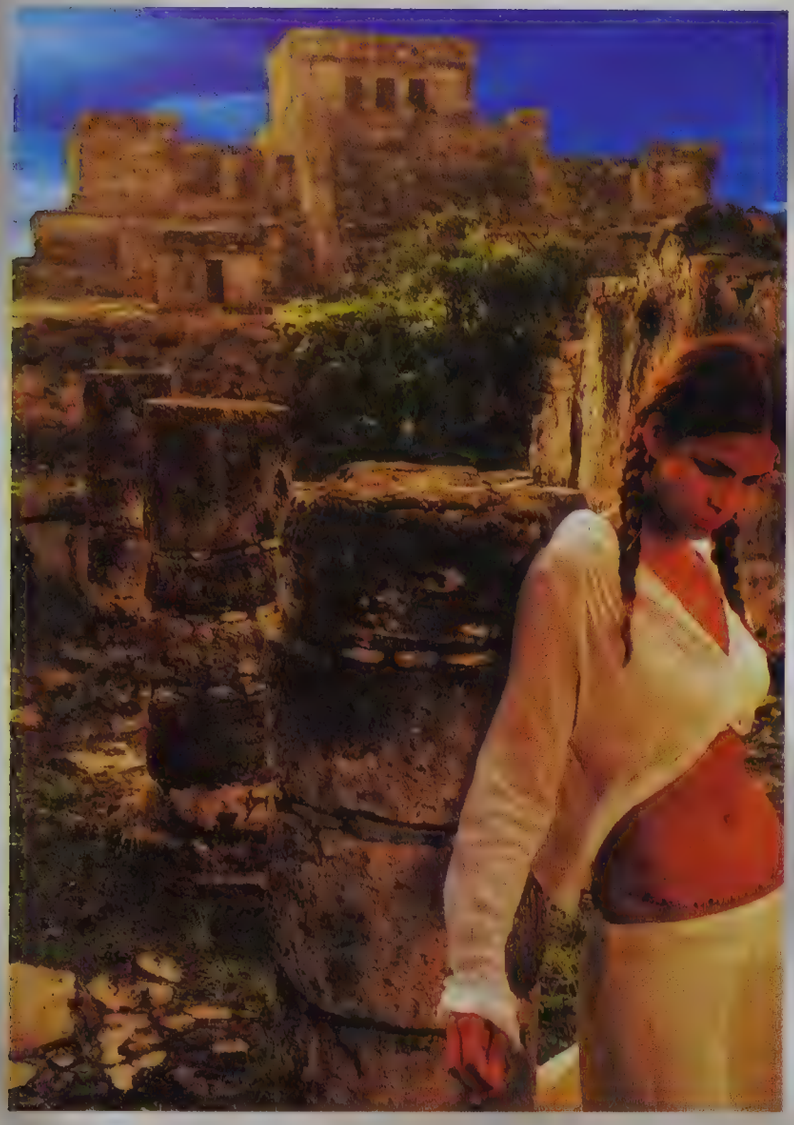

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UP FRONT

Why Music?

If music be the food of love, play on
—William Shakespeare, *Twelfth Night*

Human beings are inherently and just about universally musical. Of course, salable musical talent is not given to us all—but musical responsiveness, a musical *sense,* certainly is. The person who is unmoved (neither uplifted nor cast down) by melody and rhythm is perhaps as rare as the person who (through injury or illness) has lost the sense of taste and no longer desires food. Whether one's musical palate is tempted by offerings from Laurie Anderson, the Backstreet Boys, Miles Davis, the Budapest String Quartet, or the Buena Vista Social Club is immaterial. Music is a common craving. Hundreds and hundreds of radio stations base their existence on that premise.

Although compositional cleverness—be it Mozart's or Mariah Carey's—may be appreciated intellectually, music appeals directly and almost exclusively to the emotions. The old adage has it that music can soothe our savage breasts, but it can also open up an unhealed psychic wound, incite us to action, or hijack our better judgment (a possibility that prompted Lodovico Settembrini, the character who represents Western rationalism in Thomas Mann's great novel *The Magic Mountain,* to call music a "politically suspect" art.)

JOHN VINK; MAGNUM PHOTOS

Is our musical capacity a meaningless by-product of our intelligence? Is it hardwired? Has it something to do with sexual selection, seduction, and mating? Or (and this is the argument I find most persuasive) does it have an essentially social function? To see what anthropologists, behavioral ecologists, and neurobiologists think, please turn to "Face the Music," by Susan Milius, on page 48.—*Ellen Goldensohn*

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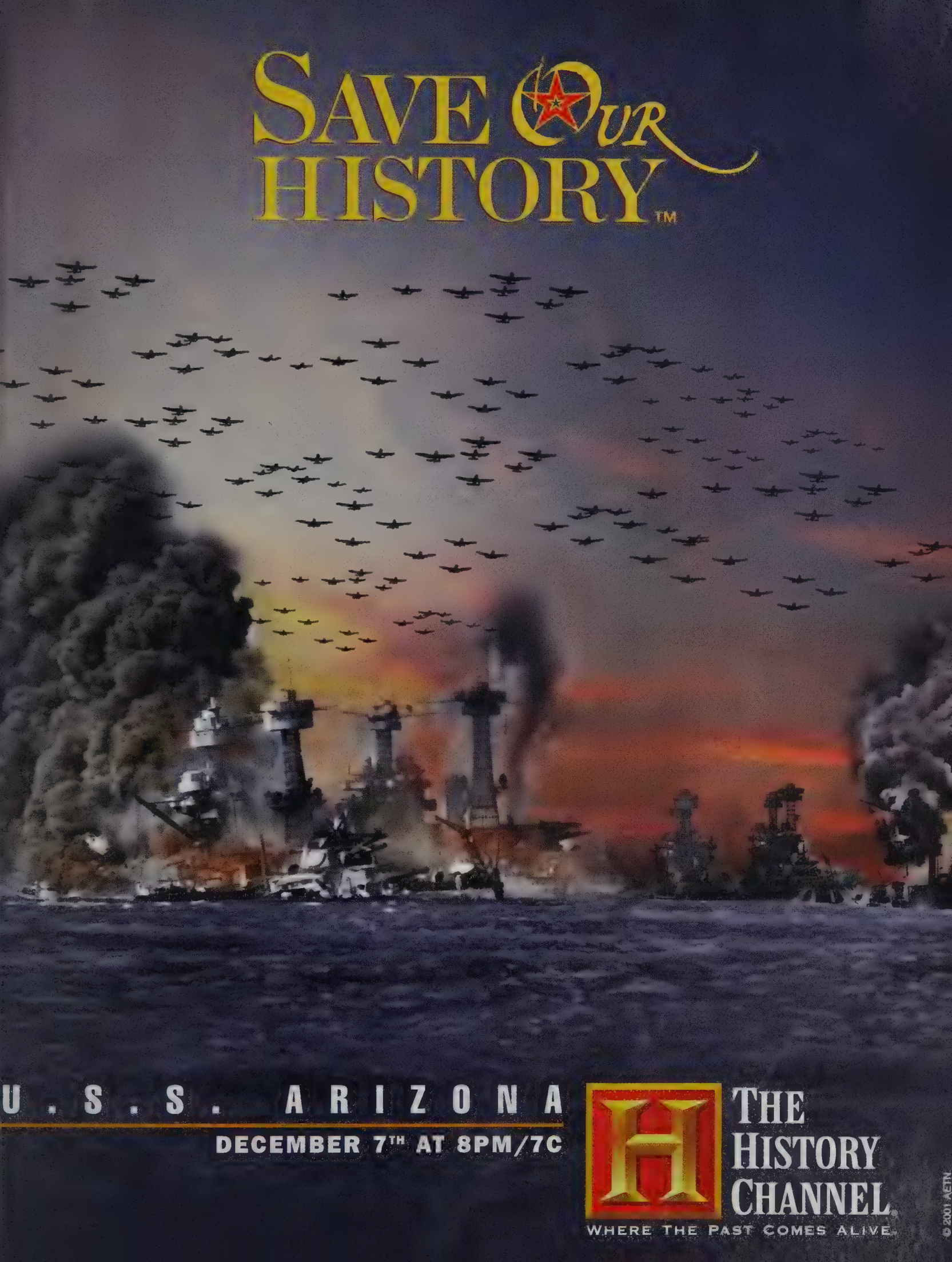
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LETTERS

A Date With a Blue Moon

I was wondering why Joe Rao did not mention, in his column "The Sky in October," that a Blue Moon occurred on October 31, 2001.

Mike Jacobs
Newport Beach, California

JOE RAO REPLIES: This was a rather unusual situation. The full Moon on November 1 occurred at 12:41 A.M. EST. Yet in the Central, Mountain, and Pacific time zones, this full Moon appeared before midnight, and hence on the previous calendar day. So for much of the country, in fact, the Blue Moon—the second full Moon in a calendar month—was in October (full Moons on October 2 and 31). At *Natural History* we have traditionally geared our Moon-phase times to the Eastern time zone, so we considered the Blue Moon to be occurring in November (full Moons on November 1 and 30). I mentioned this timing oddity in my November column.

Universal Praise

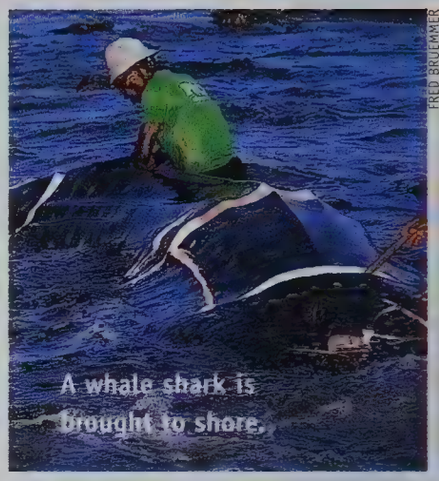
Neil deGrasse Tyson's column ("Universe") is consistently one of the best features of your magazine. I've been a *Natural History* subscriber for twenty years and a science editor for almost that long. I know great writing when I see it. Tyson makes obscure information relevant, dry material interesting, and complex details understandable. That's a tall order, given that his subject is astrophysics. "Over the Rainbow" (9/01) was a terrific example of this.

Barbara Ross
via e-mail

Fruit Fall

In "Engineering the Apple" (10/01), Sue Hubbell writes that the notion that apples caused illness "may well have been reinforced by the apple's association with the Fall in various translations of the Bible, including the King James Version (though in the oldest Hebrew and Greek texts, the Tree of Knowledge bears merely a generalized 'fruit')." As far as I can tell from *Strong's Exhaustive Concordance of the Bible,* neither "apple" nor "apples" appears in Genesis in the King James Version. However, apples are mentioned in the King James Version Hebrew Bible in Deuteronomy, Psalms, Proverbs, the Song of Solomon, Lamentations, Joel, and Zechariah. I find no reference by Strong to apples in the New Testament.

Evan B. Hazard
Bemidji, Minnesota


FRED BRUEMMER

A whale shark is brought to shore.

Good Catch

As a volunteer at a marine laboratory in Florida, I was surprised to see the animal in the photograph on page 56 of "Sea Hunters of Lamalera" (10/01) identified as a pilot whale; the patterns of ridges and spots tell me it is more likely to be a whale shark, the largest species of fish on earth.

I recently lived for four years in the Inupiat community of Barrow, Alaska. Having observed the whaling practices and traditions there, I was interested to read about Lamalera's whaling culture. The two indigenous populations are widely separated geographically, but the traditions of sharing the harvest and of concern for the prey's spirit are quite similar.

Ernie Whitney
Cortez, Florida

THE EDITORS REPLY: The photograph is indeed of a whale shark. The slide we worked from was captioned correctly by the photographer, but we mislabeled the photograph. We thank you and the other sharp-eyed readers who pointed out the error.

Natural History's e-mail address is nhmag@amnh.org.

ERICH LESSING; ART RESOURCE

Temptation of Eve by Gislebertus, ca. 1130

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CONTRIBUTORS

Although he started graduate school with the idea of studying the effects of cattle-grazing on public lands in the western United States, **Lee Dyer** ("In Defense of Caterpillars," page 42) soon concluded that caterpillars were more intriguing herbivores and that tropical forests were more alluring places. Dyer, left, is an assistant professor in the Department of Ecology and Evolutionary Biology at Tulane University in New Orleans. His long-term research projects in Costa Rica, Ecuador, and the state of Colorado—carried out with assistance from Earthwatch Institute volunteers—involve interactions among plants, caterpillars, predators, and parasitoids. **Nic Bishop,** who began taking photographs at the age of nine while living in Sudan, where his father worked for UNESCO, holds a doctorate in plant physiology. He is the author-photographer of about forty books, mostly for children, including *The Secrets of Animal Flight* (Houghton Mifflin, 1997), featuring high-speed photography, and *Digging for Bird-Dinosaurs: An Expedition to Madagascar* (Houghton Mifflin, 2000).

Susan Milius ("Face the Music," page 48) is a life sciences reporter for the weekly magazine *Science News*. She says that when she was growing up, her mother insisted the household keep quiet during broadcasts from New York City's Metropolitan Opera. "The singers sounded so miserable so much of the time," Milius remembers, that she often fled into the woods. As a result, she says, she owes much of her interest in nature to "the emotive powers of the Met's singers." Now, in addition to birdsongs and frog calls, Milius enjoys many kinds of music—from Chinese opera to her nephew's computer creations—but finds only certain recordings conducive to writing. The present article was written under the influence of Miles Davis's "Kind of Blue."

After growing up in Arizona and earning a Ph.D. in zoology at the University of California, Los Angeles, **Harvey B. Lillywhite** ("To Wipe and Wax," page 58) traded the arid Southwest for the southeast coast. Now a professor of zoology at the University of Florida and director of its Seahorse Key Marine Laboratory, he hasn't forgotten his "ecological roots"—his work with wiping frogs addresses a fascinating way of dealing with dry weather. But Lillywhite isn't ecologically constrained; he loves exploring "the raw outdoors," from mountains and deserts to islands and reefs. Currently he is studying the physiological ecology of snakes and frogs and is involved in ecology and conservation projects in northern Florida's Big Bend coastal region.

Joel Cracraft ("Gondwana Genesis," page 64) studies the evolution and biogeography of birds. His interest in the Southern Hemisphere distribution of living avian groups began three decades ago, when he was a graduate student at Columbia University and a postdoctoral fellow at the American Museum of Natural History. Since 1992, Cracraft has been a curator in the Museum's Department of Ornithology and has served as curator-in-charge since 1999. He has done fieldwork in South America and central Africa and conducted long-term studies of birds of paradise in New Guinea. Cracraft has written widely on phylogenetic theory and was co-curator of the Museum's Hall of Biodiversity.

Papua New Guinea, where marine wildlife photographer **Mike Parry** ("The Natural Moment," page 78) was born, abounds with beautiful, diminutive coral-reef creatures. Parry, though, prefers to concentrate on larger subjects and has traveled the world in search of them; two of his favorites are the great white shark and the humpback whale. A lover of blue-water free diving, Parry can spend hours trying to get just the right shot, one that he hopes "captures the animal's spirit on film." But for his photograph of a saltwater crocodile, he had little time to think before diving to within a couple of feet of the reptile.

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AT THE MUSEUM

American Icon

At the centenary of her birth, Margaret Mead is remembered as the world's most influential anthropologist.

By Nancy C. Lutkehaus

Margaret Mead arrived at the American Museum of Natural History in 1926. Having just completed her first significant ethnographic research in Samoa, she was appointed assistant curator in the Department of Anthropology. She was only twenty-five years old. Mead was given a temporary office in an attic room in the Museum's west tower. So well did she like this out-of-the-way office, with its views of the rooftops of New York City and its two stairways (ideal, she said, for creeping down one stairway while someone to be avoided, such as a too-solicitous elderly curator, was laboring up the other) that she stayed there the rest of her life.

Arriving at that same office in 1972 to be interviewed by Mead for a position as her assistant (I was an undergraduate anthropology major at Barnard College), I felt as though finding my way through the maze of the Museum and up the precipitously winding stairs to Mead's inner sanctum must have been a test she'd devised to determine my suitability. Like Mead, I soon grew fond of the office's remote location and the bird's-eye view of the busy streets below. In a way, the tower's position symbolizes Mead's relationship to the Museum and to anthropology: like the tower, which is both part of and set apart from the Museum's overall structure, Mead was part of the institution and the discipline of anthropology yet also apart from them. She felt strongly that both the Museum and her discipline must not just be a repository of artifacts but must engage in finding solutions to challenges facing society.

Over the course of her fifty-two-year association with the Museum, Margaret Mead was a scientist, curator, teacher, author, social activist, and media celebrity. The success of her first book, *Coming of Age in Samoa,* published in 1928, had thrust her into the media spotlight. The book's comparison of adolescence in the South Seas and in the United States made it a best-seller at a time when the public was concerned with the social transformations among Jazz Age youth. In the early 1950s, as television became widespread, Mead appeared on the CBS program *Adventure,* a series produced live from the Museum, to talk about trance among the Balinese and the impact of World War II on social change in remote societies of New Guinea.

Mead's flair for writing and public speaking, combined with her belief that anthropologists and museums should address contemporary social issues, led to her participation—as an expert in human behavior—in United Nations conferences and other international forums and to her acting as a consultant to institutions and organizations worldwide. She discussed the role of the scientist in society, the changing nature of the family, racial inequality, peaceful alternatives to war, population growth, environmental degradation, and the creation of humane human set-

KEN HEYMAN

Margaret Mead in the Museum's old sixth-floor storage area, 1959

tlements. Her wide-ranging concern for humanity led *Time,* in 1969, to declare Mead "mother to the world."

It is thus not surprising that when the Museum celebrated its 125th anniversary in 1995 by publishing a guidebook to fifty of its treasures, Margaret Mead herself is listed as treasure no. 38, right between the Folsom Point (treasure no. 37) and the Peregrine Falcon Diorama (treasure no. 39). The guidebook states that Mead "brought the serious work of anthropology into the public consciousness" through her books, the courses she taught at Columbia University, the articles she wrote in a monthly column for *Redbook,* and the frequent interviews with her that were published in magazines and newspapers and broadcast on radio and television.

When I visited the Museum last spring, the newly renovated Hall of the Peoples of the Pacific—which had opened in 1971, decades after Mead began planning it—had recently reopened. I was pleased to see that the hall now incorporates Mead in the exhibition. Continuous videotapes show interviews with her and about her. Photographs of Mead and the people she studied, quotes from her notes and lectures, and artifacts she collected give the viewer insights into the process of doing fieldwork and add a social and historical context to her life.

Artifacts of Mead's own life are also presented—the Presidential Medal of Freedom that she received posthumously from President Jimmy Carter, as well as her signature red cape and stick. The label reads: "In her later years, Margaret Mead regularly wore a cape and used a style of walking stick often called a thumbstick. Those two items became a familiar sight as Dr. Mead traveled about for her numerous lectures and conferences."

Margaret Mead used to joke that when she didn't want to be recognized, all she had to do was leave her cape and thumbstick at home. How fitting that she has become both a Museum treasure and an artifact.

Nancy C. Lutkehaus is chair of the gender studies program and an associate professor in the Department of Anthropology at the University of Southern California. She is the author of the forthcoming Margaret Mead and the Media: Anthropology and the Creation of an American Icon.

MUSEUM EVENTS

DECEMBER 3
Lecture: "Our Cosmic Habitat" (Distinguished Authors in Astronomy series). Astronomer Royal Martin Rees, Royal Society research professor, University of Cambridge. 7:30 P.M., Space Theater, Hayden Planetarium.

DECEMBER 4, 6, 7, 8, AND 11
Panel discussion: "Using the Genome to Understand Human Ancestry." Moderated by Nicholas Wade, *New York Times* science reporter, with anthropologist Ian Tattersall, AMNH; biologist Andrew Clark, Pennsylvania State University; Douglas Wallace, Center for Molecular Medicine, Emory University; and evolutionary biologist Joseph Graves Jr., Arizona State University West. December 4, 7:00 P.M., Kaufmann Theater. Presented in conjunction with the exhibition "The Genomic Revolution" (on view through January 1, 2002, in Gallery 3). Workshops on genetics: December 6 and 7, 9:00–11:00 A.M. and 7:00–9:00 P.M., and December 8, 9:00–11:00 A.M.; follow-up explanation session, December 11, 7:00 P.M.

DECEMBER 8
Roundtable presentation: "Border Crossing: Cultural Appropriation and Artistic Freedom in Arts, Media, and Literature of Indigenous and Latina Women" (Identities Beyond Borders series). Moderated by writer Helena Maria Viramontes, Cornell University, with artist participants Nadema Agard, Maria Dominguez, and Carol Kalafatic. 1:00–3:00 P.M., Linder Theater. Gallery visit to "Who Is the Virgin of Guadalupe? Women Artists Crossing Borders," Henry Street Settlement Abrons Art Center, 4:00–6:00 P.M. Shuttle from AMNH at 3:15 P.M. For reservations and information, call (212) 769-5315 or see www.amnh.org/programs.

DECEMBER 17
Lecture: "The Hubble Time Machine" (Frontiers in Astrophysics series). Astronomer James Lowenthal, University of Massachusetts, Amherst. 7:30 P.M., Space Theater, Hayden Planetarium.

DECEMBER 18 AND JANUARY 29
Lectures on upcoming sky events: "Celestial Highlights." Hayden lecturer and amateur astronomer Hank Bartol. 6:30 P.M., Space Theater, Hayden Planetarium.

DECEMBER 29
Kwanzaa celebration: Performances, workshops, and marketplace for this African American holiday. 12:00–6:00 P.M., Hall of Ocean Life. For a schedule of events, call (212) 769-5315 or visit www.amnh.org/programs.

JANUARY 7
Lecture: "The Riddle of the Compass" (Distinguished Authors in Astronomy series). Author and mathematician Amir D. Aczel. 7:30 P.M., Space Theater, Hayden Planetarium.

JANUARY 12–13 AND 26–27
Weekend programs: "America As Home." Arab American and South Asian community-based organizations present films, artist talks, panel discussions, and readings and performances. Leonhardt People Center.

JANUARY 15
Lecture: "One Universe." Neil deGrasse Tyson, the Frederick P. Rose Director of the Hayden Planetarium, and Charles Liu, AMNH Department of Astrophysics. 7:00 P.M., Kaufmann Theater.

JANUARY 19
Lecture/demonstration: "Through Time and Space" (Following the Beat series). Based on instruments in AMNH's Hall of African Peoples. Percussionists Neil and Ayanda Clarke. 1:00–3:30 P.M., Leonhardt People Center.

JANUARY 24
Lecture: "Aquagenesis: The Origin and Evolution of Life in the Sea." Marine biologist and artist Richard Ellis, AMNH Division of Paleontology. 7:00 P.M., Kaufmann Theater.

DURING DECEMBER/JANUARY
The Museum's Origami Holiday Tree, decorated with 1,500 folded-paper animals, is on display in the Theodore Roosevelt Memorial Hall.

Teachers resource: *Musings,* a Web newsletter for science educators, at www.amnh.org/learn/musings.

University Without Walls: Telephone courses on natural sciences and anthropology. The Museum's Department of Education and DOROT, a nonprofit serving the elderly. For information, call DOROT at (212) 769-2850 or toll-free (877) 819-9147.

Field trips, walking tours, and workshops for children and adults, both inside and outside the Museum. Call (212) 769-5200 for information.

Planetarium courses (beginning in January): "How to Choose a Telescope," "Stars, Constellations, and Legends," and many others. For complete course descriptions, visit www.amnh.org/hayden/.

For news from the Center for Biodiversity and Conservation, go to research.amnh.org/biodiversity/center/newsletter/webletter.html.

The American Museum of Natural History is located at Central Park West and 79th Street in New York City. For listings of exhibitions, public programs, and hours, call (212) 769-5100 or visit the Museum's Web site at www.amnh.org. Space Show tickets, retail products, and Museum memberships are also available online.

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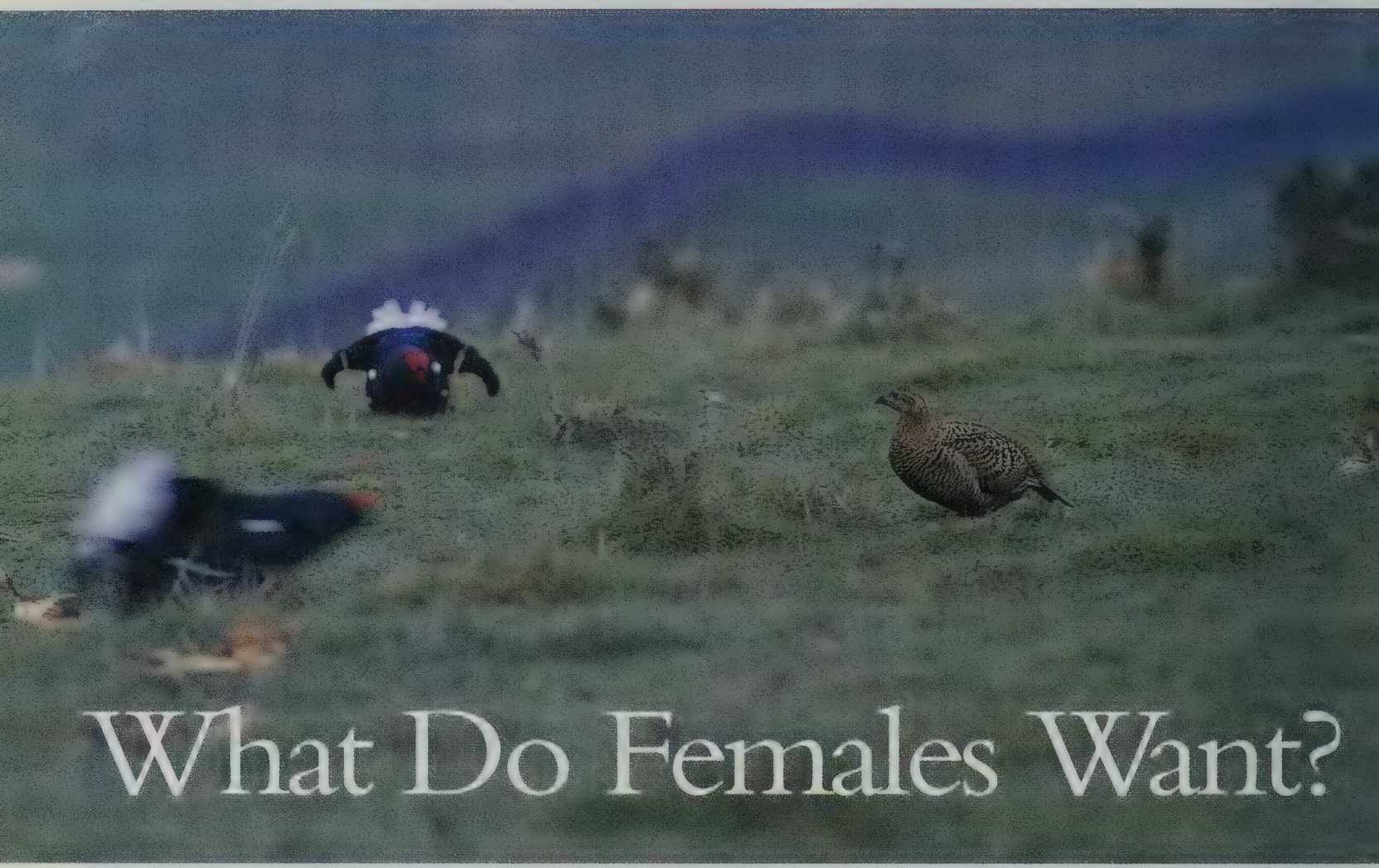


What Do Females Want?

Does a male's long tail or flashy coloration advertise his good genes? New research challenges the old answers.

By Robert M. Sapolsky

To readers of *Cosmo* and *Animal Behaviour,* it must be quite obvious that females the world over are concerned about finding the right mate. For females in pair-bonding species (such as swans, which mate for life, or monogamous South American monkeys), competency at fatherhood is a potential mate's most desirable quality. In many of these species, courting males display paternal skills: male lovebirds, for example, snatch worms and pretend to feed them to a desired female.

But selecting a good co-parent is also high on the list for female *Homo sapiens*—a species that hardly rates as a textbook pair-bonder. About a decade ago, psychologist David M. Buss published a celebrated study examining the attributes that men and women desire in a mate. He canvassed more than 10,000 people, from thirty-seven different cultures—people of different races, religions, and ethnicities; people living in urban and rural settings, Western and developing nations, capitalist and socialist economies, monogamous and polygamous family arrangements. And in every society Buss examined, he found that women were more likely than men to consider economic prospects a high priority in a mate. This was interpreted as a sign that human females universally want mates who will be effective breadwinners. (As one might imagine, Buss's study generated all sorts of unsettling accusations of political incorrectness.)

And even in social species that don't pair off to reproduce, females often choose a particular male on the basis of how well he is likely to treat them or their offspring. For a female olive baboon, for example, a prize catch would be a male that, when in a foul mood, directs his aggression toward some other female rather than toward her. But what about species in which a female isn't going to be getting any paternal assistance out of her mate or even having much contact with him down the line? In such species, males are not integrated into social groups. (The typical arrangement, such as that of golden hamsters, is a

BOBBY SMITH; ARDEA LONDON, LTD.

Male black grouse attempt to impress a female.

stable group of females with a single breeding male that is likely to be booted out by some other male long before his own young are born—a social structure that sociobiologists typically call a harem but that primatologist Alison Jolly suggests should instead be called a "gigolo group.") All the female gets out of the brief liaison with her mate is some sperm packed with genes. So what does such a female desire in a male? Good genes, of course. The age-old problem for these females is how to figure out which males have the good genes, and in species after species, males try to advertise theirs. Peacocks spread their gorgeous tail fans; male lions have their elaborate manes, elk their ornate antlers. But are such features merely ornamental, serving no useful purpose beyond sexual attraction? The question that has long vexed evolutionary biologists is whether these ornaments actually tell you anything about the genetic health of a male. In other words, is there truth in advertising?

In 1930 British statistician and geneticist Ronald Fisher, one of the most influential evolutionary thinkers of the past century, postulated that fancy ornamentation is actually something a female should *not* be attracted to, because a male animal's huge energy expenditure to grow and maintain it would have a price tag in terms of his survival—his Darwinian fitness. According to this view, if the male has spent a lot of calories on growing the biggest tail or antlers or whatever, he couldn't possibly have spent enough on something sensible, such as keeping his immune system well tuned. While Fisher's view has generally fallen out of favor, some striking support for it has recently emerged. Robert Brooks and John Endler, of James Cook University in Australia, studied sexual attractiveness in male guppies of the species *Poecilia reticulata*. They first showed that the males with the fanciest color patterns were considered the most attractive by females and that they sired sons that were likely to be especially attractive. Color patterning, the scientists determined, is heritable and may be sex-linked, coded for by a cluster of genes on the male's Y chromosome. Then Brooks found something that was surprising enough to get published in the journal *Nature* (6 July 2000): sons of attractive males are significantly *less* likely to survive than are average *P. reticulata* males. And it isn't even the case that once they get this ornamentation, they are more likely to be killed by a predator (a frequent cost of being flashy and conspicuous). Their survival rates are lower than average even *before* they reach sexual maturity and develop the coloration. So Brooks's guppy experiment stands as one example in support of the significant cost of attractive ornamentation.

> The son of an attractive male guppy is significantly less likely to survive than the average male.

Another view is that such decorations don't tell you much—good or bad—about a male's genes. Rather, they say something about fads. Jacob

A female guppy (left) and a male

PAUL ZAHL; PHOTO RESEARCHERS, INC.

Höglund and Arne Lundberg, of Uppsala University in Sweden, thought up an interesting experiment. Pair up female and male black grouse that have no chemistry—the female isn't interested in the male. Now use low-tech scientific artifice to turn him into a male that appears to be highly desirable—that is to say, surround him with ostensibly rapt females (a gaggle of stuffed female birds)—and that indifferent live female suddenly decides he's kinda cute after all. It's a bandwagon effect. This seems to mean that if all the other females of your social group decide that males with neon antlers are a hot commodity (even if you think they look ridiculous), it is to your fitness advantage to mate with someone like that. After all, if neon antlers on males are suddenly all the rage, you want your sons to have them in order to maximize the passing on of copies of your own genes. By this circular logic, a trait becomes attractive because it's attractive because it's attractive . . . even if it carries no information about the health or genes of the carrier.

Still another possibility is that attractive ornamentation really does translate into something meaningful and desirable about a male. Health may be the message: "You can bet I'm in good health if I can afford to waste all this energy growing these three-foot-long tail feathers." In 1982 Marlene Zuk and W. D. Hamilton, one of the gods of evolutionary biology, formalized this into the notion that conspicuous and expensive ornamentation in males signaled that they were free of parasites (see "A Charming Response to Parasites," April 1984). Why should a female find this appealing? Because it decreases the likelihood that *she'll* wind up with parasites after cozying up to the guy. All sexually reproducing organisms need to worry about sexually transmitted diseases; the more evolutionarily significant version of this basic theme is that attractive ornamentation signals not only good health but good genes to be passed on to the next generation. Evolutionary biologist Amotz Zahavi, of Tel Aviv University in Israel, posits that females have evolved the ability to differentiate between ornamentation that genuinely reflects good genes and the kind that instead suggests bad genes or an acquired trait.

Does attractive ornamentation sometimes translate into good genes? Theoretically, at least two methods could give you the answer to this question. Using the first, you isolate the gene(s) responsible for the attractive trait in males of a certain species. You then look for other genes that are clustered nearby and that tend to be inherited along with the attractiveness gene(s) in a statistically reliable way. You figure out the function of the proteins coded for by those neighboring genes and whether these proteins are particularly advantageous. And soon you'll be part of some zillion-dollar race to sequence the animal's genome.

FRANS LANTING; MINDEN PICTURES

Peacock and peahen

Or you can do it the old-fashioned way. Carry out a study in which females are mated and have offspring with males of differing attractiveness. Then see whether the attractive males father young that are more "fit"—that is, more likely to survive to adulthood and to produce their own offspring. If they do, you've got a pretty good reason to conclude that the more attractive males pass on a more adaptive assemblage of genes. And this is exactly what a number of studies have shown, casting a big vote in favor of the good-looks/good-genes hypothesis.

Yet some startling revisionism has recently crept into that hypothesis. One example is a study of ducks, done by Emma Cunningham and Andrew Russell, then of the University of Sheffield, and also published in *Nature* (2 March 2000). They found that the offspring of male mallards that were particularly attractive to females have a trait that considerably increases their likelihood of survival. So, more votes for the good-looks/good-genes hypothesis. What was that trait? When females mated with these males, they laid large eggs, a factor that definitely increases the fitness of the offspring. But wait—egg size is a trait determined by the *female,* not the male. When females mated with more attractive males, they apparently invested more energy in the resulting offspring, making it more likely that these young would survive. In fact, when Cunningham and Russell controlled for egg size, they found no difference in survival between the offspring of the most and the least attractive males.

> When zebra finch females mated with attractive males, they produced eggs with more growth-promoting hormone.

In a similar study published in the journal *Science* (1 October 1999), Diego

WILLIAM PATTON/SURVIVAL ANGLIA; OXFORD SCIENTIFIC FILMS

Gil and colleagues at the University of Saint Andrews in Scotland studied zebra finches and found that the offspring of the more attractive males begged for more food, grew faster, and were more likely to be dominant once they fledged. Again, where is this coming from? The scientists found that when females mated with the more attractive males, they developed eggs that contained more growth-stimulating hormone. And then there's the work by Félix de Lope, of the Universidad de Extremadura in Spain, and Anders Møller, of Université Pierre et Marie Curie in France, showing that when female barn swallows mate with more attractive males, they take better care of the resulting chicks.

All this is actually a logical extension of the bandwagon effect uncovered by Höglund and Lundberg. For starters, if everyone in your species "wants" to mate with males that have some trait that doesn't necessarily seem attractive to you, it's still in your best genetic interest to mate with these males so that your sons have the desirable trait. And if everyone in your species "knows" that more attractive males make for offspring that carry better genes, and if you've mated with an attractive male, it's in your best genetic interest to invest as much as possible in the well-being of those offspring.

The challenge, of course, is to figure out how a female knows she has mated with a more attractive male and how this translates into the differential investment in her young. How does that "knowledge"—on whatever level it exists in the brain of a bird—translate into synthesizing more growth hormone in a gland or going the extra mile to find the offspring something to eat? We have here the classical dichotomy between a proximal and a distal level of explanation in biology. The distal level—large, evolutionary concerns—is simple. By investing more in offspring with traits that are more reproductively desirable, females can enhance the passing on of their genes. But the proximal level—how that evolutionary logic translates into the nuts and bolts of hormones and neural pathways in a particular animal—is a great mystery at this point.

Studies of egg size, the amount of growth hormone in eggs, and parental investment generate serious problems for the good-looks/good-genes hypothesis. When Cunningham and Russell found that females with attractive mates grew bigger eggs, at first it raised the possibility that the underlying logic was, "Everyone knows that more attractive males make kids with better genes, so I have to make sure these kids survive." But the researchers then found that the father's attractiveness had no effect on hatching success, survival, or growth. Maybe good genes really *don't* exist.

Findings such as Cunningham and Russell's do not disprove the theory that more attractive males have better genes; quite possibly they do, most of the time. But these findings have uncovered a major alternative explanation for what has been observed—one that must now be ruled out in every subsequent study on the subject: if the offspring of attractive males are more fit, is it because the female has invested more energy in their survival?

So lots more research is needed, both to see how much the parental investment factor confounds the supposed cases of good genes and to understand the physiology behind females' differential investment in offspring and how it relates to the attractiveness of the father. In the meantime, exasperation seems unavoidable. It's bad enough that males with longer tail feathers get more action, but they also get acclaimed for having better genes when this may not actually be the case.

Self-fulfilling prophecies spring up in all sorts of settings. Everyone "knows" that boys are biologically better at math than girls are, and studies have shown that teachers are more likely to praise young boys than young girls for the same math performance. And guess what? By the time they reach high school, boys score better than girls on standardized math tests. Is this due to a biological difference or to the different environment? Here's another example that has always amused me (it's from the medical anthropology literature): In certain traditional cultures, everyone "knows" that shamans are able to induce voodoo death (aka psychophysiological death). So when someone has a voodoo hex put on him, everyone knows he's a goner, and they withhold food from him—why waste a limited resource?—to the point of his weakening and dying from one ailment or another. Is such a death due to the efficacy of a voodoo curse or to this additional intervention? Not clear, but you can bet the shaman's hex fees go up.

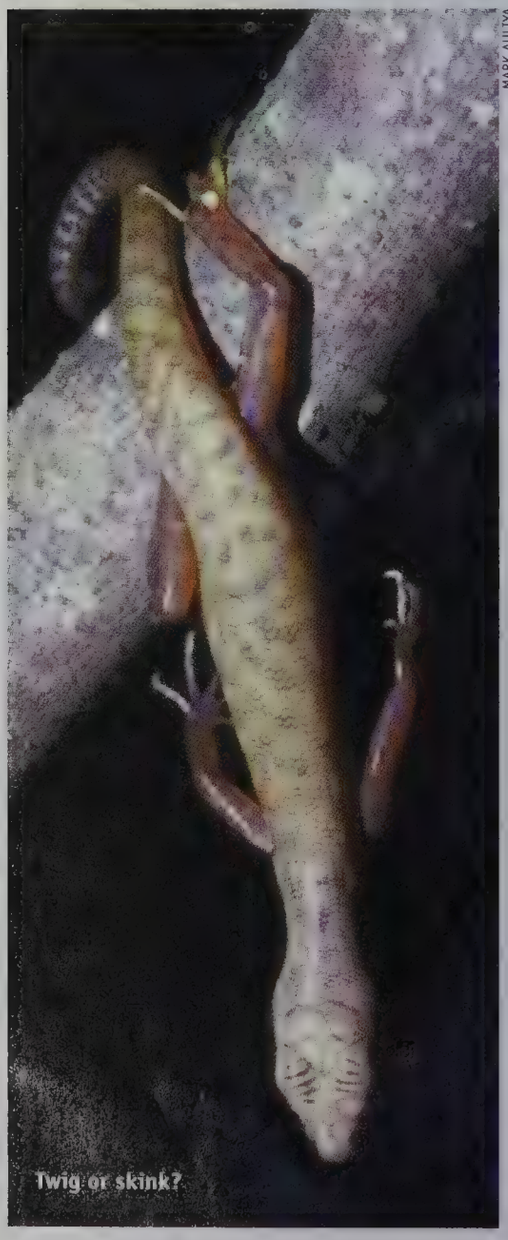
One sees such confusions popping up in all sorts of realms of human illogic. I'm just disappointed to see female mallards and zebra finches falling for something this obvious. They should know better than that.

Robert Sapolsky is a professor of biology and neurology at Stanford University. His latest book is A Primate's Memoir (Scribner, 2001).

IN SUM

TWIG MIMICS Reptiles have evolved an assortment of strategies for discouraging, avoiding, or escaping from predators. Certain snakes have bright colors that warn of venom; others feign death when threatened. Many lizards have sharp spines, and some attempt to frighten predators with sounds. Still others opt to run away and hide.

Andreas Schmitz and Mark Auliya, from the Zoologisches Forschungsinstitut und Museum Alexander Koenig in Bonn, Germany, recently described the unusual escape tactics of the shy diurnal skink *Sphenomorphus sabanus*. Auliya observed this behavior in a swampy forest in West Kalimantan, Indonesia, while he was studying another reptile species. One night he happened to see, by the glow of a flashlight, an *S. sabanus* scampering along the branch of a tree, attempting to flee. Then it stopped suddenly and hung upside down; clinging to the branch with its hind claws, the lizard resembled a small, dry twig. After a few moments, it stopped doing its twig impression and darted away. The finding was hardly a surprise to local villagers—they confirmed that these skinks use imitation to avoid detection.

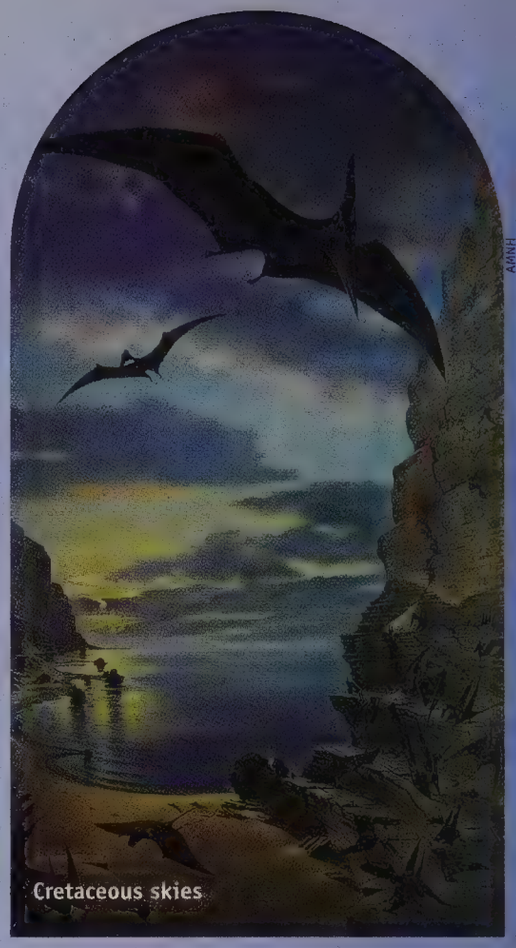

MARK AULIYA

Twig or skink?

Even though a few species of geckos also mimic twigs or leaves to avoid predators, the strategy is quite rare. Most lizards that reside in trees drop to the ground when threatened. The researchers suggest that the advantage of *S. sabanus*'s escape route may be its novelty. If predatory birds expect their prey to fall to the ground, Schmitz and Auliya's argument runs, they would be unlikely to notice a lizard still hanging from a branch. The cryptic posture might make these skinks invisible to tree-dwelling predators as well. ("An Unusual Escape Reaction Observed in *Sphenomorphus sabanus* [Reptilia: Scincidae] in Indonesia, With Taxonomic Comments," *Herpetological Bulletin* 76, 2001)—*Kirsten L. Weir*

PTREMENDOUS A recent dig near Valencia, Spain, has uncovered a previously unknown pterosaur that may be the largest animal ever to have taken wing. Workers digging in siltstone dating from the very late Cretaceous found vertebrae and limb bones indicative of a new species and genus of azhdarchid pterosaur, with the wingspan of individual adults ranging from sixteen to forty feet. This degree of variation is typical of several genera of flying reptiles, but the width is the greatest yet seen (the largest previously known specimen, *Quetzalcoatlus northropi*, had a wingspan of thirty-six feet). David Unwin, of Humboldt-Universität zu Berlin in Germany, one of the researchers who made the find, is suggesting that the variable and sometimes great size of these pterosaurs may be attributable to the animals' unusual sensitivity to their environment during growth.

Unwin's suggestion would account for both the variation within species and the size of the largest individuals. The duration and extent of growth in modern turtles, crocodiles, and other groups related to the pterosaurs is heavily influenced by environment (temperature, food availability), and Unwin thinks that pterosaurs shared that susceptibility, even though adult body size in other groups of flying vertebrates, including both living and extinct bats and birds, varies little and is largely independent of environmental influences. (Abstracts of "A Giant Azhdarchid Pterosaur From the Latest Cretaceous of Valencia, Spain—The Largest Flying Creature Ever?" and "Variable Growth Rate and Delayed Maturation: Do They Explain 'Giant' Pterosaurs?" Sixty-First Annual Meeting of the Society of Vertebrate Paleontology, 2001)—*T. J. Kelleher*


AMNH

Cretaceous skies

HOME SWEET FOSSIL HOME Large or small, landlubbers or seafarers or both, hermit crabs have one feature in common: they generally spend their lives inside the empty shells of snails or other mollusks. When these crabs grow too large for one adopted home, they search for another. But if high-quality shells are in short supply, they must improvise. Some make do with a broken shell or even with a piece of bamboo or a hollow mangrove root. Now there is evidence that at least one type of hermit crab has found another solution.

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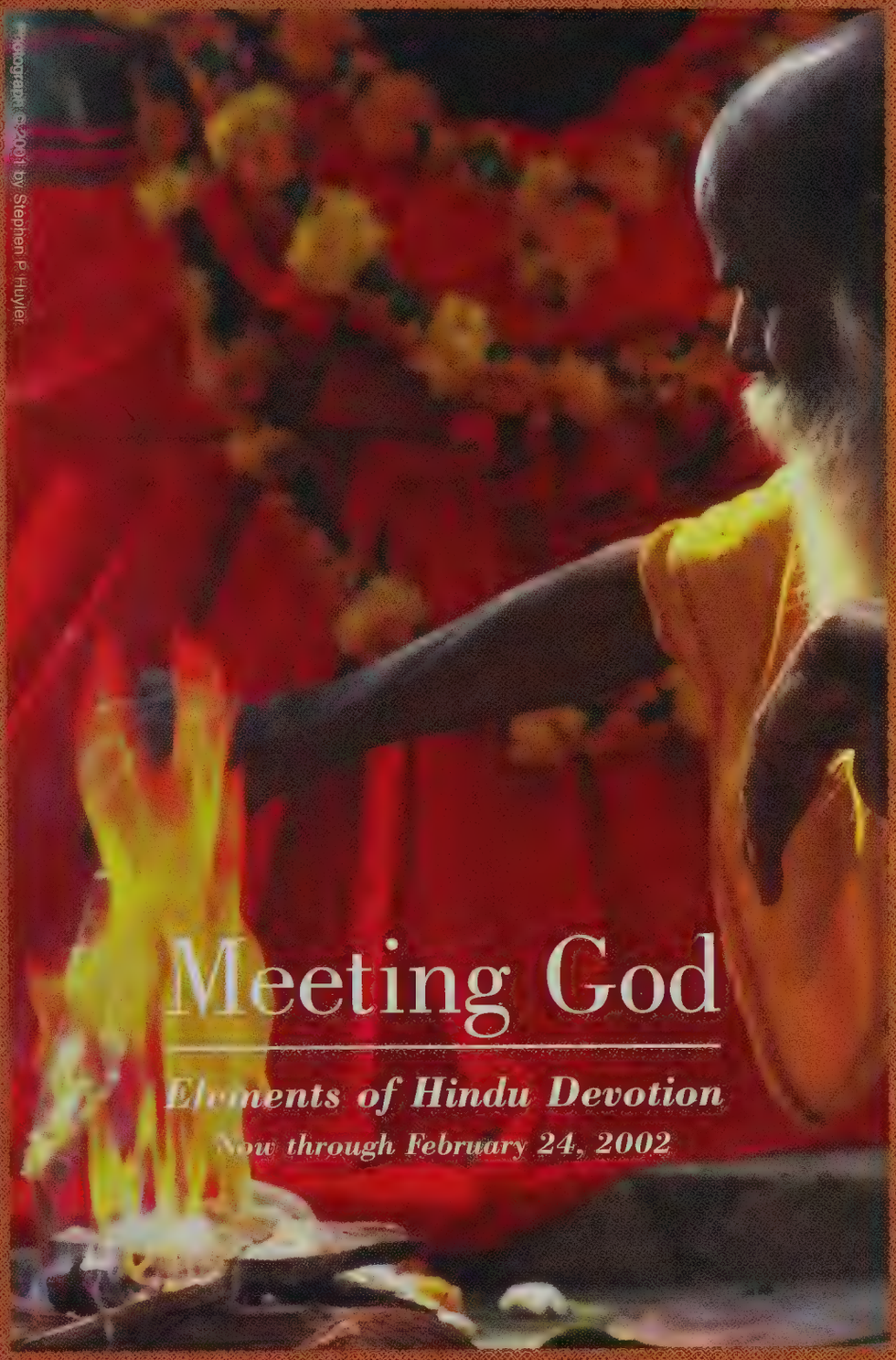

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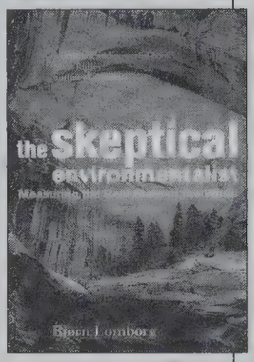

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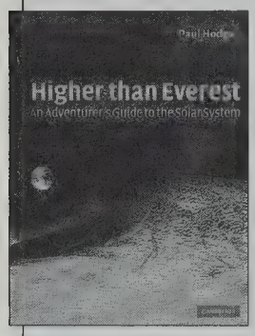

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Zoologist David K. A. Barnes, of University College Cork in Ireland, recently discovered that the large, semiterrestrial hermit crab *Coenobita rugosus* sometimes moves into fossilized marine snail shells that have fallen out of the eroding coastal limestone of southwestern Madagascar.

Barnes found that the crabs preferred the shells of local mollusks, but when these mod-

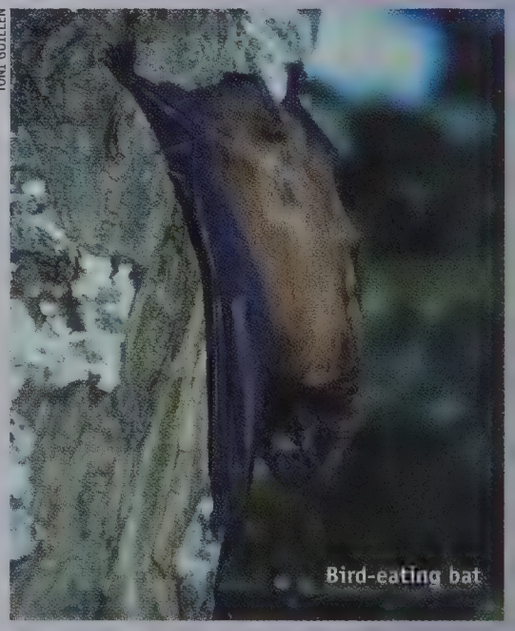
DAVID K.A. BARNES

ern homes weren't available the hermits inspected fossil shells for suitability and sometimes moved into them (though nearly all the fossils Barnes examined had structural hindrances that made them unusable). He predicts that this curious behavior may eventually change, however. Local fishermen collect mollusks along the shore and, working at the high-tide mark, remove the living animals from their casings, leaving behind piles of empty shells. Most are too large for hermit crabs. But as fishermen increasingly exploit the local mollusk populations, they'll soon have to settle for smaller animals. In time, the discarded shells may be diminutive enough to provide homes for hermit crabs, freeing them from the need to survey the emerging fossils. ("Ancient Homes for Hard-up Hermit Crabs," *Nature* 412, 2001)—*Kirsten L. Weir*

IN-FLIGHT MEAL Though bats and birds are both aerial creatures, records of their interaction have been extremely rare. Carlos Ibáñez, of the Estación Biológica de Doñana in Seville, Spain, and fellow researchers have demonstrated that a large, carnivorous European bat is interacting regularly with certain groups of birds. In a massively messy undertaking, these scientists have sifted through 14,000 guano samples from the bat species known as the greater noctule *(Nyctalus lasiopterus)*, hoping to identify what the bats were feeding on every night: flies, moths . . . birds? They found that the bat droppings contained quite a few feathers, particularly during the two periods a year when flocks of small passerines make their seasonal migrations, mainly at night, through the bat's Mediterranean domain.

A few species of tropical bats occasionally capture and consume roosting birds, but *N. lasiopterus* is the only bat now known to regularly prey on birds in temperate climates. It may in fact hunt and attack a bird while both animals are in flight.

Ibáñez's group studied the wing shape and sonar patterns of the greater noctule and found that they differ significantly from those of other carnivorous bats. *N. lasiopterus* has a long, low-frequency echolocation call, making it well equipped for detecting airborne prey at considerable distances. In addition, the wings of the greater noctule—designed for speed—lack the maneuverability that would be required for hunting a bird in a confined nesting space. According to Ibáñez et al., this rare bat made an easy transition from hunting large insects to capturing small birds in midair. ("Bat



TONI GUILLÉN

Predation on Nocturnally Migrating Birds," *Proceedings of the National Academy of Sciences* 98:17, 2001)—*Erin M. Espelie*

HOW TO SAY I LOVE YOU Firefly courtship is built on bioluminescence, but scientists are unsure what controls the glow. Fireflies are flashers, and their abdominal lantern, or light-producing organ—permeated by nerve cells

and equipped with a trachea—is made up of cells containing luciferin, a protein that emits light in the presence of oxygen. Just inside the walls of these cells, called photocytes, are masses of mitochondria—the cells' powerhouses—which need oxygen to do their work. Normally they grab hold of any incoming oxygen. Until recently, no one knew how oxygen could pass deep into the photocytes, where the luciferin is, and cause the cells to glow.

KEITH KENT/SPL; PHOTO RESEARCHERS, INC.

Barry Trimmer, of Tufts University, and colleagues became interested in the process after noticing similarities between caterpillars' brain cells, which use nitric oxide (NO) as a signal, and the cells controlling the fireflies' lantern. They found that exposing live fireflies to NO gas caused the lantern to glow continuously. Many insects synthesize NO for use as a neurotransmitter; whether this molecule signals the fireflies' photocytes to glow wasn't clear. Even when the insects' nervous system was removed and the lantern exposed to NO, the organ still glowed—indicating that NO gas was not causing nerves to fire. Introduction of octopamine, a known firefly neurotransmitter, caused flashing, which was stopped by adding a substance that absorbed the NO. The scientists speculate that NO bonds more readily to the mitochondria than oxygen does; unable to bond there, oxygen drifts to the organelles that house the light-emitting luciferin. As for why the flash stops, they propose that either the increased oxygen accelerates degradation of NO or that the flash of light may reverse the bonding of the gas to the mitochondria. ("Nitric Oxide and the Control of Firefly Flashing" and "NO Helps Make Fireflies Flash," *Science* 292, 2001)—*T. J. Kelleher*

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THIS LAND

FALLS FROM PARADISE

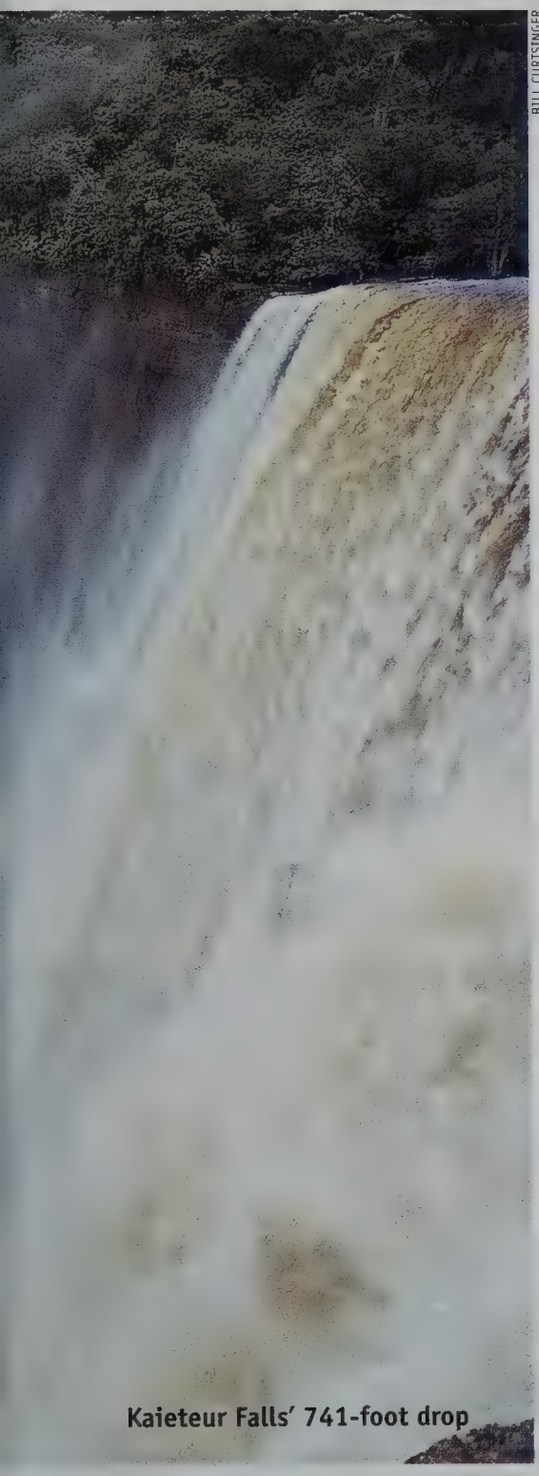
Guyana's Kaieteur Falls is a remote yet accessible wilderness.

By Steve Fratello

About 150 miles inland from the coast of Guyana (formerly British Guiana), the Potaro River plunges 741 feet in one drop over a sandstone cliff. This is Kaieteur Falls, one of the most spectacular cataracts in the world. According to a legend of the Patamona Indians, it was named for Kaie, a chief who saved his people by paddling over the falls in an act of self-sacrifice to Makonaima, the great spirit. Upriver from the falls, the Potaro Plateau stretches out to a distant escarpment of the Pakaraima Mountains, while below yawns the great Kaieteur Gorge, swathed in luxuriant rainforest.

As a naturalist who has visited Guyana's interior many times, I have had the good fortune to linger in this wilderness on several occasions. Although hiking down into the gorge presents something of a challenge, an airstrip on the plateau enables anyone to see the falls, a one-and-a-half-hour flight by small plane from Georgetown, the nation's capital. A national park was established in 1929 to protect the area, and recent legislation expanded the total coverage to 242 square miles. Although the park exists more on paper than in reality, plans are being drawn up to conserve its unique community of plants and animals and to develop ecotourism.

The 1,500-foot-high Potaro Plateau lies within the eastern Guiana Highlands, which cover most of southeastern Venezuela as well as the



BILL CURTSINGER

Kaieteur Falls' 741-foot drop

bordering territory in northern Brazil and western Guyana. In this huge area, more ancient rock is largely overlain by the Roraima Formation—rock (mostly layers of sandstone) that erodes relatively easily. This has resulted, particularly in Venezuela, in the creation of the famous *tepuis*—sheer-sided, table-topped mountains that, like islands, bear distinctive vegetation.

On the plateau, patches of sandy soil near the falls support both scrubby forest and savanna that contains grasses, sedges, scattered shrubs, some small trees, and areas of exposed rock where vegetation appears during the rainy season. Right next to the savanna, at the brink of the gorge, is a patch of low-elevation cloud forest. Sustained by the mist from the falls, it drips with epiphytes—mosses, ferns, aroids, orchids. Farther upriver the alluvial forest is dominated by the large-buttressed mora tree, while the forest in the gorge below is mixed or dominated by species of wallaba.

A number of terrestrial orchids live on the savanna, but the most eye-catching plant is *Brocchinia micrantha,* a thick-stalked terrestrial bromeliad that can grow twelve feet high. Found here and at some nearby areas, this plant collects water in a "tank" formed by the base of its leaves. The tank is often home to the small golden frog *(Colostethus beebei)* and to the world's largest bladderwort, *Utricularia humboldtii.* The bladderwort's lavender flowers adorn a stalk that may rise six feet above the bromeliad's tank.

Among the animals on the plateau is the savanna fox, a species widespread in South America and only distantly related to the foxes of the Northern Hemisphere. It is better known as the crab-eating fox—only because the first specimen described had a crab in its stomach. While sightings of this and other mammals are apt to be rare on a short visit, by sitting at the edge of the escarpment one might observe a troop of red howler monkeys moving quietly through the canopy far below.

More likely to be seen or heard on the plateau is the little chachalaca, a gallinaceous bird named in part for its noisy call. The rocky forest and rock outcrops near the falls provide the perfect habitat for the Guianan cock-of-the-rock, a medium-sized, flaming orange bird. During the breeding season, small groups of males gather in leks (courting areas), where they display for the females. I have seen four or five males together in one small, scrubby tree close to Johnson's Lookout, a vantage point that affords a picture-postcard view of the falls.

From the escarpment, one can also see birds flying across the gorge—such as red-and-green macaws. I've observed a pair of orange-breasted falcons that nest on the cliff face next to the falls. They probably prey mainly on the white-collared and other swifts that make their home on the cliffs and behind the falls. These insect-eating birds fill the air at dawn and dusk, and

FLIP DE NOOYER; FOTO NATURA

An aerial view

as night falls they sweep down at amazing speed to settle in their roosts.

Butterflies, including glorious morphos, abound in the gorge. In one ravine, within a few minutes, I've spied nearly all the seven or eight species of morphos present, among them *Morpho hecuba,* South America's largest butterfly, with wings that span eight inches. The upper side of this majestic glider is a rich dark brown, with a flamelike burst of russet and pearl. Blue morphos include *M. rhetenor,* whose glittering royal-blue wings are among the most brilliant sights on earth.

Standing deep in the gorge on a white sand beach, with the dark waters of the Potaro roiling by, I've surveyed lush green glades of grasses and sedges that line rocky side channels of the river. I've watched as the *Inga* trees at the river's edge, their contorted branches heavily laden with epiphytes, attracted myriad butterflies and skippers to their delicate blossoms.

JOE LEMONNIER

Looking across the river to the billowing crowns of the mighty mora trees, I've let my gaze wander up the green slope to a smaller falls called Old Man's Beard, which cascades in tiers off the escarpment. All this plus Kaieteur Falls—if this isn't a paradise on earth, what is?

Naturalist Steve Fratello has explored various rainforests, especially within the Neotropics. During 2000 he led several butterfly- and moth-collecting expeditions into remote mountain regions of Guyana.

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HABITATS

Guianan cock-of-the-rock
JAN VERMEER; FOTO NATURA

Savanna vegetation, in addition to the bromeliad *Brocchinia micrantha* and the bladderwort *Utricularia humboldtii,* includes such terrestrial orchids as the pale green and purple *Catasetum discolor* and the large pink *Sobralia liliastrum.* Common scrubby trees are *Erythroxylum citrifolium, Andira grandistipula,* and species of *Clusia.* Among the herbs are the insectivorous *Drosera kaieteurensis,* a sundew; the saprophytic *Burmannia bicolor;* and countless grasses and sedges.

Boggy areas are often dominated by *Brocchinia reducta,* a cousin of *B. micrantha.* This terrestrial species collects water in its tall, narrow, yellowish tank. Also at home here are plants of the Rapateaceae family, which is endemic to Guyana and neighboring regions. The Rapateaceae usually have long, straplike leaves and a small cluster of light yellow flowers topping a long stalk.

Forest trees prominent on the plateau and in the gorge include mora, wallaba *(Eperua falcata, E. grandiflora),* clump wallaba *(Dicymbe pharangophila),* and species of *Swartzia* and *Inga*—all legumes. The souari nut tree, *Caryocar nuciferum,* is also common. Well buttressed, it is easily recognized by its large fruit, pockmarked bark, and bright-green trifoliolate leaves.

Mammals, apart from the savanna (or crab-eating) fox, live mostly in the forested areas of the plateau or down in the gorge. Among the primate species are red howler and wedge-capped capuchin. Peccaries, tapirs, anteaters, armadillos, sloths, coatis, and others are around but hard to see. Southern river otters swim in the Potaro's dark, tea-colored water.

Birds easily encountered on the plateau near the falls include the little chachalaca and Guianan cock-of-the-rock, as well as honeycreepers, dacnises, and tanagers. The cliff face is home to the orange-breasted falcon and its prey—white-collared swifts, white-chinned swifts, and white-tipped swifts. In the gorge, red-and-green macaws and red-billed toucans are common sights, while occasionally spied down along the river are the white-necked jacobin and the crimson topaz, both hummingbirds. In one spot deep within the gorge, the pendulous nests of green oropendolas adorn the outer branches of a tall tree growing on one of the river's small islands. These nests and this large songbird's melodious, liquid calls are signatures of the Neotropical lowlands.

Morpho menelaus
LUIZ MARIGO; PETER ARNOLD, INC.

Butterflies include *Morpho hecuba, M. rhetenor, M. menelaus,* and *M. achilles.* Among the innumerable other species are *Aphrissa statira, Phoebis argante,* and half a dozen *Parides.*

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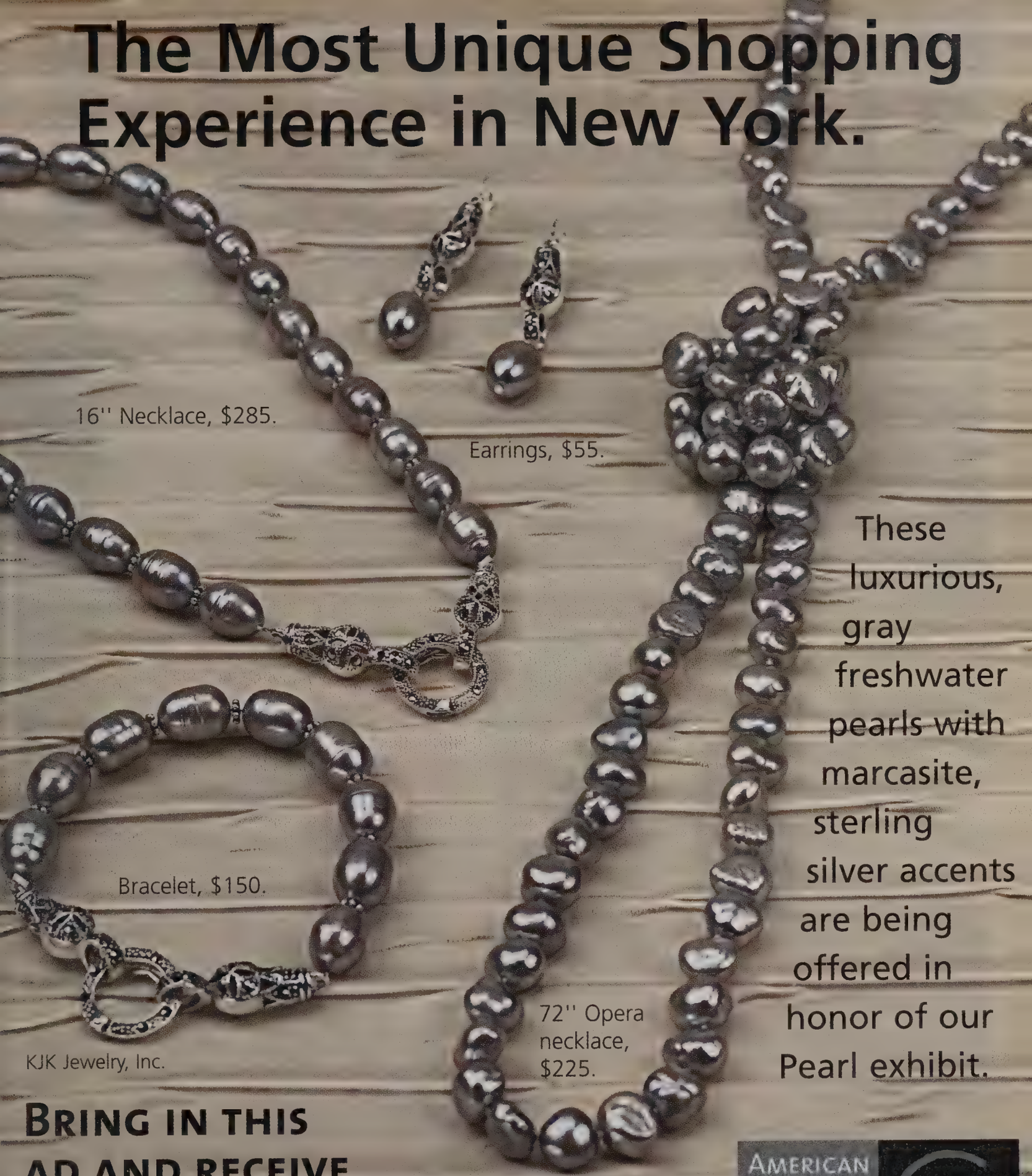

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UNIVERSE

Mathematically challenged Americans suffer from . . .

Fear of Numbers

By Neil deGrasse Tyson

ROBERT GROSSMAN

We may never know the circuit diagram for all the electrochemical pathways within the human brain. But one thing is for sure, we are not wired for logical thinking. If we were, then mathematics would be the average person's easiest subject in school.

In this alternate universe, math might not be taught at all, because its foundations and principles would be self-evident even to slow-achieving students. But nowhere in the real world is this true. You can, of course, train most humans to be logical some of the time, and some humans to be logical all of the time; the brain is a marvelously flexible organ in this regard. But people hardly ever need training to be emotional. We laugh early in life, and we are born crying.

We do not emerge from the womb enumerating objects around us. People had to invent the concept of counting and build upon it when new needs arose because of the growing complexities of life and society. We all agree that $2 + 3 = 5$, but what is $2 - 3$? To answer this question without saying it has no meaning required that somebody invent negative numbers, another part of the number line. And we all know that half of ten is five, but what is half of five? To give meaning to this question, somebody had to invent fractions, yet another class of numbers. As the ascent through numberdom progressed, many more kinds of numbers were invented: imaginary, irrational, transcendental, and complex, to name a few. They each have specific and sometimes unique applications to our discoveries about the physical world.

Those who study the universe have been around from the beginning. As a member of this (second) oldest profession, I can attest that we actively use all parts of the number line for all manner of heavenly analyses. We also routinely invoke some of the smallest and, of course, largest numbers of any profession. One could argue strongly that astrophysicists do not fear numbers.

With thousands of years of culture behind us, what grade has humanity earned on its math report card? More to the point, what grade do we give Americans, members of the most technologically advanced culture the world has ever known?

Let's start with airplanes. Whoever lays out the seats for Continental Airlines seems to suffer from medieval

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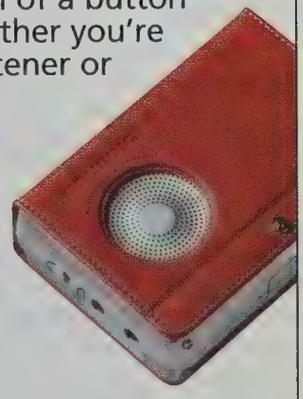

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fears. I have yet to see a row 13 on any flights I have taken with them. How about buildings? Seventy percent of all high-rises along a three-mile stretch of Broadway in Manhattan have no thirteenth floor. While I have not compiled detailed statistics for everywhere in the nation, my experience walking in and out of buildings tells me that more than half of them skip the thirteenth floor. If you've ridden the elevators of these guilty high-rises, you've probably noticed that the fourteenth floor directly follows the twelfth. This trend exists for new buildings as well as old ones. Some buildings are self-conscious and try to conceal their superstitious ways by providing two separate elevator banks: one that goes from 1 to 12 and another that jumps straight to 14. The twenty-two-story apartment building in which I was raised (in the Bronx) has two separate banks of elevators. One bank stops on the even floors, the other on the odd floors. One of the mysteries of my childhood was why the odd bank of elevators went from floor 11 directly to floor 15 and the even bank from 12 to 16. Apparently, for my building, a single odd floor could not be skipped without throwing off the entire odd-even scheme. Hence the blatant omission of any reference to either the thirteenth *or* the fourteenth floor.

In one particular building that harbors an extensive subterranean world, the levels below the first floor are labeled B, SB, P, LB, and LL. Perhaps this is to give you something to think about while you are standing in the elevator doing nothing, but these floors are begging to become negative numbers. For the uninitiated, the abbreviations stand for Basement, Sub-Basement, Parking, Lower Basement, and Lower Level. We don't use such lingo for regular floors. Imagine a building with floors labeled not 1, 2, 3, 4, and 5 but Ground, Above Ground, High Ground, Very High Ground, and Sub-Roof. There should be nothing wrong, in principle, with floors called -1, -2, -3, or even 0.

Society's implicit denial of all that is less than zero shows up in many places. A mild case of this syndrome exists among car dealers who, instead of saying they will subtract $1,000 from the price of your car, promise you $1,000 "cash back." In corporate accounting reports, fear of the minus sign is pervasive. There it's common practice to enclose negative numbers in parentheses and not to display the negative symbol anywhere on the spreadsheet. Even the successful book and film *Less Than Zero,* which tracks the falling from grace of wealthy Los Angeles teens, could not be imagined with the logically equivalent title *Negative.*

Just as we hide from negative numbers, we hide from decimals, especially in America. This past year was the first time that all stocks were traded on the New York Stock Exchange in decimal dollars instead of in clunky fractions. And even though U.S. currency is decimal and therefore metric, we don't think of it that way. If something costs $1.25, we typically parse it and recite "a dollar twenty-five." This behavior is not fundamentally different from the way people recited prices in the old decimal-averse British system that combined pounds, shillings, and pence.

When my daughter turned fifteen months old, I took perverse pleasure in telling people she was "1.25." They would look back at me, heads tilted in silent puzzlement, the way dogs look when they hear a high-pitched sound.

Fear of decimals is also rampant when probabilities are communicated to the public. People usually report odds in the form of "something to 1," which makes intuitive sense to nearly everyone: The odds against the long shot winning the ninth race at Belmont are 28 to 1. The odds against the favorite are 2 to 1. Yet the odds against the second-favorite horse are 7 to 2. Why don't the track's oddsmakers say "something to 1"? Because if they did,

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Ellen Goldensohn, Editor in Chief

then the 7-to-2 odds would instead read "3.5 to 1," stupefying the decimal-challenged people of this nation.

I suppose I can live with missing decimals, missing floors in tall buildings, and floors that are named instead of numbered. A more serious problem is the limited capacity of the human mind to grasp the relative magnitudes of large numbers.

If you start counting by reciting one number per second, you will need 12 days to count to a million and 32 years to count to a billion. Counting to a trillion will take you 32,000 years, which is as much time as has elapsed since people first drew on cave walls. If laid end to end, the 100 billion (or so) hamburgers sold by the McDonald's restaurant chain would stretch around the Earth 275 times, with enough left over to make a stack from Earth to the Moon and back. And last I checked, Bill Gates was worth $50 billion. If the average home-owning adult would pick up a quarter from the sidewalk but not a dime, then the corresponding amount of money that Bill Gates would ignore if he saw it on the street is $25,000.

In corporate accounting reports, fear of the minus sign is pervasive.

These are entertaining brain exercises for the astrophysicist, and normal people do not think about these sorts of things. But at what cost? Beginning in 1967, NASA launched a series of space probes that shaped more than two decades of planetary reconnaissance in our solar system. The celebrated Pioneer, Voyager, and Viking missions were part of this era. So, too, was the *Mars Observer,* which was lost on arrival in the Martian atmosphere in 1993. Each probe took many years to plan and build. Each mission had broad and deep scientific objectives and cost taxpayers between $1 billion and $2 billion. After a 1990s change in administration, NASA introduced a "faster, cheaper, better" paradigm for a new class of $100 million space probes. Unlike previous probes, these could be planned and designed swiftly to fulfill missions with sharply defined objectives. Of course, that meant a mission failure would be less costly and less damaging to the overall program of exploration.

In 1999, however, two of these more economical Mars missions failed, with a hit to taxpayers of about $250 million. Yet public reaction was just as negative as it had been to the loss of the billion-dollar *Mars Observer.* The news media reported the $250 million as an unthinkably huge waste of money and proclaimed that something was wrong with NASA. The result was a congressional hearing.

Not to defend failure, but $250 million is not much more than the cost of producing Kevin Costner's film flop *Waterworld.* It's also the cost of about two days in orbit for the Space Shuttle, and it's one-fourth the cost of the lost *Mars Observer.* Without these comparisons, and without the reminder that these failures were consistent with the "faster, cheaper, better" paradigm, in which risks are spread among multiple missions, you would think that $1 million equals $1 billion equals $1 trillion.

Nobody announced that the $250 million loss amounts to less than one cent (0.01 dollars) per person in the United States. This many pennies are surely lying around in our streets, but people are just too busy to bend down and pick them up.

Astrophysicist Neil deGrasse Tyson is the Frederick P. Rose Director of New York City's Hayden Planetarium and a visiting research scientist at Princeton University.

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CELESTIAL EVENTS

Where the Action Is

If you don't like the weather on Jupiter, just wait.

By Richard Panek

Let's face it, the night sky doesn't do much. Sure, the stars appear to execute one rotation on the celestial sphere every twenty-three hours and fifty-six minutes. And yes, the planets, as the Greek derivation of the word suggests, wander slightly against the starry backdrop from one night to the next. And then there's the Moon, forever going through its fractional phases, over and over, unto eternity. But *action*? Put all these incremental changes together, and what you get is a drama of Noh-like minimalism, at most.

This helps explain why a favorite target of many amateur observers is the one telescopic object they know will actually change right before their eyes: Jupiter. Last month, this column described Galileo's discovery of the moons of Jupiter in January 1610, when the telescope was still in its infancy. Even that primitive telescope revealed the constant dance of Jupiter's four innermost moons, a piece of celestial choreography that visibly varies not only from night to night but over the course of a single evening. For amateur observers, Jupiter's moons offer the astronomical equivalent of an old saw, "If you don't like the weather, just wait." So does Jupiter itself—especially because part of what's always changing on the planet is, in fact, the weather.

Take the Great Red Spot. It's a cyclonic storm similar to a hurricane (though its 15,400-mile diameter is large enough to swallow two Earths). The spot churns counterclockwise at speeds of up to 270 miles per hour. A constant presence—at least during the four centuries since the invention of the telescope—the Great Red Spot undergoes visible changes in shape, size, and even color. In recent years, it has appeared not so much red as bleached orange.

And the spot is only the most famous manifestation of Jupiter's volatile meteorology. Other storms arise frequently, sometimes drifting across the planet's atmosphere, sometimes growing from one day to the next, and sometimes simply popping out of existence. Cloud formations, too, are constantly shifting. Dark bands such as the north and south equatorial belts reveal where gases are descending, while white zones show where gases are rising. But even if Jupiter's atmospheric conditions were as calm as Colin Powell, the planet would still reward observers looking for action.

Jupiter, with a diameter of 88,789 miles at its equator, is the largest planet in the solar system, but despite its size, its rate of rotation is the fastest: it completes one revolution every nine hours and fifty-five minutes. Under ideal circumstances, an observer could watch an entire day pass on Jupiter in the course of one night on Earth.

Such circumstances arise during December and January. At 1:00 A.M. Eastern Standard Time (EST) on New Year's Day, Jupiter reaches opposition—the point in a planet's orbit at which

JET PROPULSION LAB; NASA

Earth lies between it and the Sun. When that happens, observers on Earth can see a planet "in front of" them only when the Sun is "behind" them. Because Jupiter will be rising at sunset and setting at sunrise—a length of time that on some of the longest nights of winter happens to pretty much coincide with the planet's orbital period—observers will be able to see Jupiter's full rotation. What's more, this particular opposition of Jupiter finds the planet passing just about as close to Earth as it ever does, providing amateur observers with a generous target, forty-seven arc seconds wide.

The best opportunities to monitor the passage of a Jovian day in its entirety arise during the week before and the week after opposition—in this case, the last week of December and the first week of January. During that period, the planet will be high enough above the horizon throughout the crucial dusk-to-dawn time frame that watchers shouldn't be hindered by the significant blurring created by Earth's atmosphere when objects are low in the sky. Select a feature to monitor (a band, a belt, a storm), then follow it as it moves across the planet's visible disk, slips out of view, eventually reappears, and returns to its initial position. On New Year's Eve, for instance, the Great Red Spot will be crossing the planet's central meridian (the imaginary vertical line running from pole to pole down the center of the disk) at 7:06 P.M. EST and returning to the meridian at 5:01 A.M. EST on New Year's Day.

As always, the only obstacle standing between you and a good round of observations is the weather. Not there; here. But, hey, if you don't like the weather—well, you know what to do.

Richard Panek's next book, *The Invisible Century: Einstein, Freud, and Our Search for Hidden Universes,* will be published in 2003 by Viking.

THE SKY IN DECEMBER AND JANUARY

By Joe Rao

Mercury is scarcely visible until the last several days of December, when it creeps above the southwestern horizon about half an hour after sunset. During the first half of January, the planet shows up there more clearly near the end of evening twilight. Mercury reaches its greatest eastern elongation from the Sun (19°) on January 11, shining at a moderately favorable magnitude of -0.6 but fading rapidly to magnitude +0.3 by the 17th and to +1.3 by the 20th. It then swings down in front

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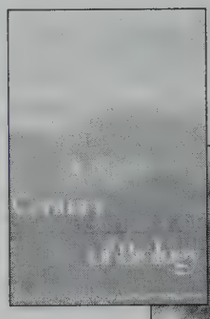

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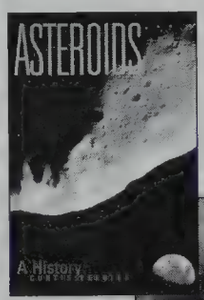

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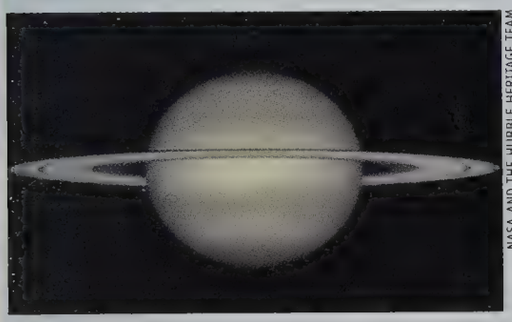
of the Sun, reaching inferior conjunction on the 27th.

Venus briefly appears very low in the east-southeast just before sunrise during the first few days of December. It then moves behind the Sun, reaching superior conjunction on January 14, and won't be readily visible again after sunset until at least late February.

Mars moves from Capricornus into Aquarius on December 4, crossing the meridian at about sunset. Look for it in the southwestern sky during the late evening hours. On the 20th, the planet is about 5° above the slim crescent Moon; a month later, on the evening of January 18, it returns to a similar position. Throughout January, Mars crosses the meridian about an hour before sunset and is visible low in the southwestern sky until about 10:00 P.M. local time. Indeed, the red planet sets at nearly this hour until the end of May. As of mid-January, Mars is 149 million miles from Earth and thus presents a rather tiny telescopic disk (last June, when it was unusually close to Earth, the planet looked four times as large). Mars gradually fades from magnitude +0.4 on December 1 to +0.8 on January 1 and finally to +1.0 on January 31.

Jupiter, in Gemini, arrives at opposition to the Sun on New Year's Day, shining at a dazzling -2.7 magnitude. In December it rises during evening twilight and remains in the sky all night. By January the planet is already shining in the east when darkness falls; passing overhead before midnight, it sets before sunup. Jupiter is the silvery "star" hovering about 5° below and to the left of the Moon on the evening of December 2. The planet is roughly the same distance above and to the right of the Moon on December 30 but appears much closer by January 26.

Saturn, at opposition, is above the horizon from sunset to sunrise on the night of December 3, passing north of the bright orange star Aldebaran. Over the course of the month, it appears to move westward several degrees. Approaching perihelion (on July 26, 2003) with its rings tipped 26° to our line of sight, Saturn shines at magnitude -0.5, the brightest it has been in nearly three decades. During January, Saturn is well up in the east-northeast at dusk; by month's end, it



NASA AND THE HUBBLE HERITAGE TEAM

sets in the west-northwest at about 3:00 A.M. local time. Observers in the continental United States and parts of southern Canada get to see a nearly full Moon occult Saturn on December 28 at about 4:05 A.M. in the East and at roughly 12:15 A.M. local time on the West Coast. For Hawaii, occultation occurs the previous evening at 8:42 P.M. local time.

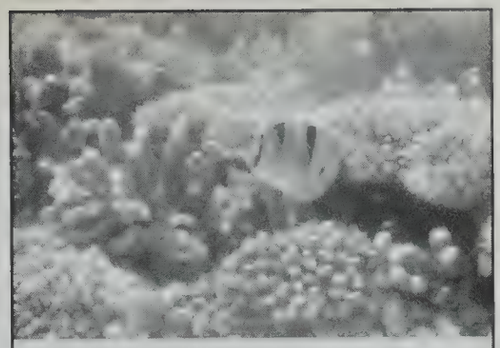
The Moon is at last quarter on December 7 at 2:52 P.M. and new on the 14th at 3:47 P.M. First-quarter Moon falls on the 22nd at 3:56 P.M. On December 30 the Moon is full at 5:41 A.M.; a few minutes earlier, the Moon is partially eclipsed, resulting in a brief, slight darkening of its lower rim at 5:29 A.M. In January, last-quarter Moon comes on the 5th at 10:54 P.M., new Moon on the 13th at 8:29 A.M., first quarter on the 21st at 12:46 P.M., and full Moon on the 28th at 5:50 P.M. On January 14 the sliver of a very young Moon hovers less than 6° below Mercury in the west-southwest. The following evening, it is well to the east of Mercury and much easier to spot.

The Geminid meteor shower promises a fine display, at least for those willing to brave the chill. These meteors can be seen all night long for a week or so, with no Moon to spoil the view with its glare. Peak activity is expected December 13–14 from evening through morning, when a Geminid meteor should burst across the sky about every minute, especially in the predawn hours. Past displays have featured a richness of both fireballs and faint meteors but have included fewer objects of medium brightness. The meteors appear to originate near the bright star Castor, in Gemini.

The Sun will undergo an annular, or ring-shaped, eclipse on December 14. The eclipse path first strikes Earth over the middle of the Pacific Ocean. Heading east, it passes 300 miles south of the Hawaiian Islands, producing an 84 percent eclipse over Honolulu at 9:27 A.M. Hawaiian time. Veering northeast, the path goes over parts of Nicaragua and Costa Rica, where the Sun will mimic a dazzling ring of fire near sunset. Over most of the United States—except for upstate New York, portions of New England, and Alaska—a partial solar eclipse will be visible. Depending on your location, between 1 and 40 percent of the Sun's diameter may be covered, with the greater coverage visible toward the south. East of the Mississippi River, sunset comes before the eclipse is finished, but the western half of the country has an uninterrupted view.

Earth reaches perihelion—at 91,402,515 miles, the point on its orbit nearest the Sun—at 9:00 A.M. on January 2.

Unless otherwise noted, all times are given in Eastern Standard Time.



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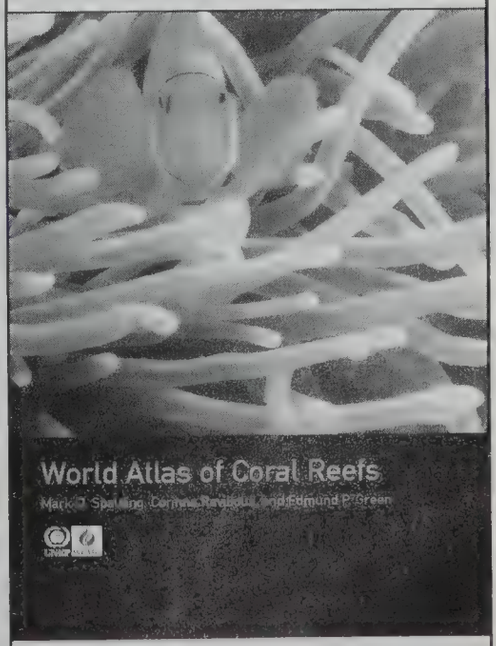

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IN THE FIELD

O Tannenbaum

Father Christmas may be at odds with Mother Nature.

By Bernd Heinrich

Along with its religious significance, the Christmas season offers those of us who live in northern latitudes a more secular, but also traditional, cause to celebrate. We have once again endured the longest nights of the year and can look forward to coasting down on ever longer days from the winter solstice to spring. To mark this event, people of northern Europe and North America have customarily gone into the forest and cut down a young evergreen tree to bring home.

For my family in New England, the holiday doesn't begin until Christmas Eve. We go into a nearby woods where the trees grow thickly, fell a six- to ten-foot conifer, and carry or drag it back to the house. We always select either a spruce or balsam fir that is not too tall and skinny from struggling to reach the sunlight. Our preferred tree is broad at the base, evenly conical, and well filled in with branches in successive whorls.

While its needles (actually modified leaves) are still alive and fresh, we decorate the tree with colorful glass globes, tinsel, red winterberries from a deciduous holly, spruce and fir cones, and cotton to simulate snow. The long, thin limbs bend slightly under their ornamental load the same way they bow, rather than break, under accumulations of snow and ice in the woods. The top is crowned with a star.

We enjoy choosing our wild tree as much as we do decorating it. But

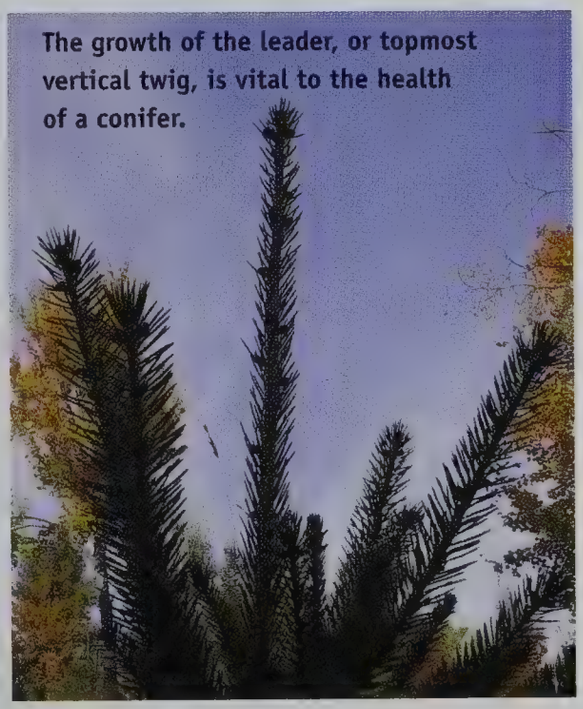
Young spruce au naturel

PHOTOGRAPHS BY NATHAN FARB

increasingly, going into the woods to find just the right specimen is a family ritual out of reach for most people. While city dwellers and suburbanites can make an annual tradition of selecting and purchasing a tree from a vendor, I wonder if this may lead us to forget what an authentic evergreen looks like. Farmed Christmas trees can be manicured with clippers or power saws into any desired shape. Ironically, the shape that is most in demand in a commercial tree is what we think a Christmas tree is supposed to look like when left to grow on its own. That is, the trees are pruned in an attempt to improve on nature. To me, that seems somewhat like painting roses red.

An unaltered conifer is unmistakable if one is aware of how its shape is achieved naturally. And shaping starts at the top. By late summer and on through fall and winter, each fir, spruce, or other conifer is topped by a single, pencil-like vertical twig bearing a cluster of buds. This twig is the "leader" that will eventually become part of the trunk of the tree. (The trunk below the young leader consists of a series of previous annual leaders.) While any bud—or any twig resulting from it—has the potential to become a leader, usually the centermost one will have assumed leadership by spring. The buds on the sides of the same top cluster will end up becoming one whorl of the horizontal branches of the tree. How these arboreal leader/lateral decisions are made is a matter of physiological checks and balances that involve a host of plant hormones interacting in response to the position of the tree in the forest and to resources such as light.

The leader releases auxins, hormones that work in conjunction with others called gibberellins to promote elongation in the leader while inhibiting the growth of nearby buds and twigs. This shunting of resources to the leader is known as apical dominance, and without it, an evergreen would burgeon equally in all directions. In a shaded forest, where each young tree competes with thousands of other seedlings, such indiscriminate growth would spell suicide. The evergreens next to it, growing conically and relatively straight up, would rob it of light. The only way any one conifer can survive the competition—and only a tiny percentage make it—is to come to a narrow point at the top and to extend sideways only far enough to capture the sun's energy. The tree's priority is to allocate energy to the leader so that the whole organism can outstretch the other trees in the race toward the light.



The growth of the leader, or topmost vertical twig, is vital to the health of a conifer.

Leadership, however, is not irreversible. Changes occur routinely, due for the most part to deer or moose nipping off the succulent tops of young trees (in winter I have also seen red squirrels feeding on the buds of the leading twigs) or to breakage caused by storms and fallen branches. In such cases, one might expect chaotic growth in all directions, but a corrective mechanism kicks in to prevent it. In a tree left leaderless and with newly uninhibited lateral growth, several shoots from the top cluster engage in a competition to become the new leader. It is a slow process, sometimes taking a few years to complete. Eventually one or another of the contenders gets a slight upper hand, so to speak: it produces more auxins than the others do, and these accumulate on the twig's lower side, causing the cells to elongate. This favored twig then bends toward the vertical to take on the role of leader. Coniferous symmetry can be restored, and the tree can again stretch skyward and compete with its evergreen neighbors.

A commercial Christmas tree starts out like any other conifer, but the tips of both its leader and lateral branches are clipped off. Such trimming removes the growth inhibition of buds and twiglets farther in on the branch. The trees direct less energy upward and outward and become bushier. With its natural branching patterns disrupted, the tree is, strictly speaking, no longer a wild specimen. To a pagan purist like me, that spoils the effect. The evergreen tree, once symbolic of forest wildness, has been tamed into a bush.

Should I care if this representation of the natural world that we bring into our living rooms is altered to suit human expectations? Probably not. But we may come to prefer and even insist on a domesticated tree with the "perfect" shape, a tree we would never see in nature. Which leads me to wonder: If our ignorance of how conifers grow can allow us to do this to a Christmas tree, how much more might we alter Nature at large without caring, or even knowing, that it has been changed?

Bernd Heinrich is a professor of biology at the University of Vermont, Burlington.

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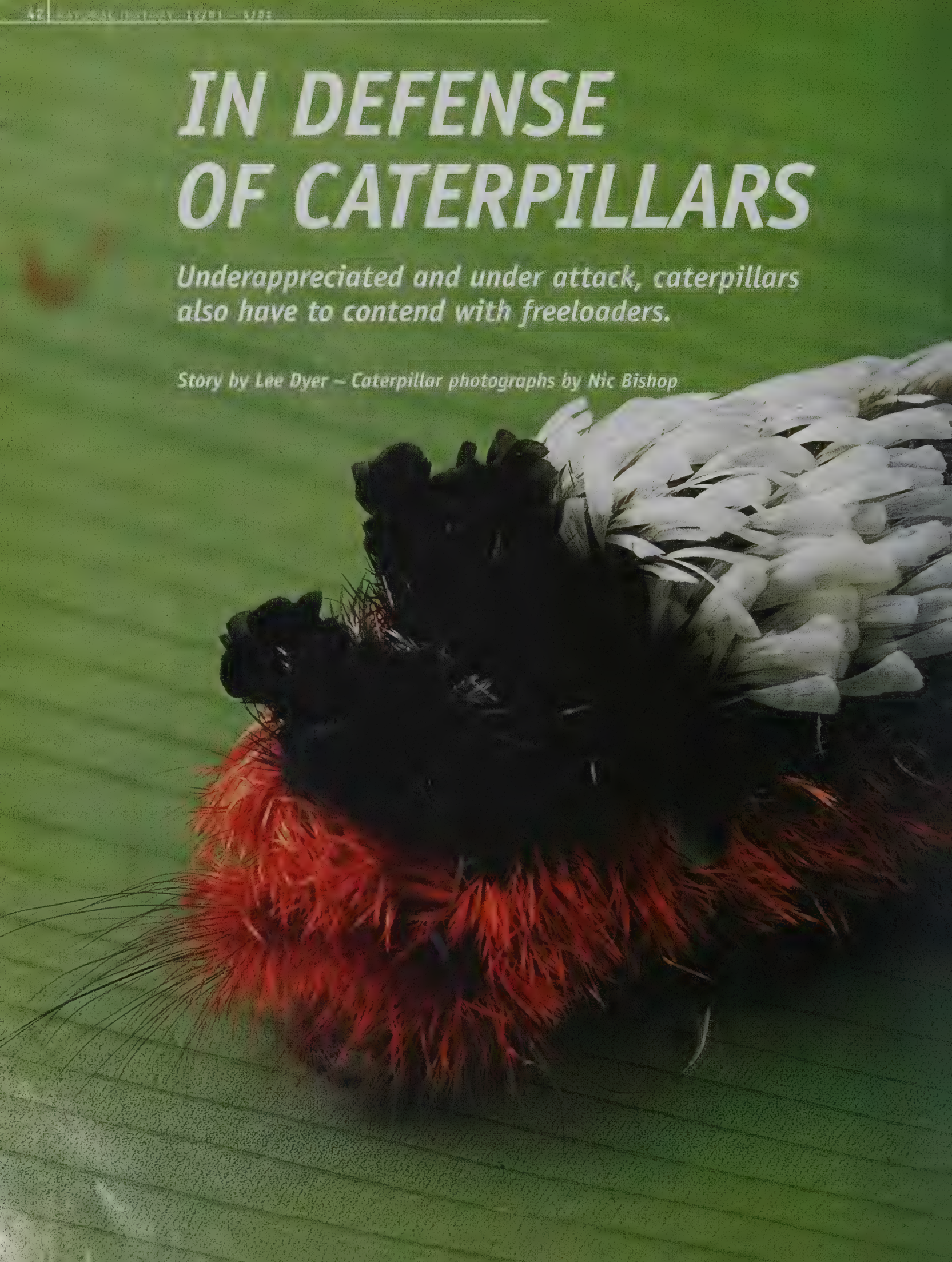
IN DEFENSE OF CATERPILLARS

Underappreciated and under attack, caterpillars also have to contend with freeloaders.

Story by Lee Dyer — Caterpillar photographs by Nic Bishop



Sticky hairs help protect a moth caterpillar from its enemies. Some other caterpillars have hairs or spines bearing chemical compounds that keep away a variety of predators. Long hairs also act as early-warning systems, giving caterpillars an opportunity to drop to the ground, thrash, or jump away when approached by an enemy.

A giant tropical ant *(Paraponera clavata)* can inflict a vicious sting, strong enough to immobilize prey. But the sticky hairs on a *Tarchon* moth larva prevent the ant from properly grasping its prey and delivering its stinging message.

The mandibles of *P. clavata* are rendered temporarily useless by a mouthful of sticky hairs, courtesy of the intended prey. Sticky hairs don't work as well against most parasitoids, whose larvae grow inside and ultimately kill their caterpillar hosts.

Heliconius hecale zuleika, a caterpillar in the long-winged butterfly family, stores toxins from the plants that it eats; it also advertises its toxicity to experienced predators in black and white. An enemy that ignores the conspicuous warning is liable to be met with a nasty blast of regurgitated plant compounds.

Agaraea larvae feed en masse: Group feeding can reduce an individual caterpillar's exposure to predators and enhance defenses such as thrashing and biting. One downside of group dining is that chemical signals from the larvae and their frass (excreta) can attract parasitoids. Some species of larvae eject their frass great distances to avoid discovery.

Many caterpillars are cryptically colored to match their host plants, making it difficult for birds and reptiles to spot them. But those predatory insects that locate prey through chemical sensing are not deterred. Using caterpillars such as this well-camouflaged *Adelpha,* the author and his collaborators have reared a plethora of fly, wasp, and nematode parasitoids.

The protagonist of Eric Carle's illustrated children's book *The Very Hungry Caterpillar* is what we all expect a caterpillar to be: a green, wormy eating machine that someday will be transformed into something better, such as a butterfly. Most people's attitudes toward caterpillars are based on this sort of lowly image and range from distaste (for, say, large hornworms munching on tomatoes in the garden) to indifference (toward, say, buckeye larvae chomping on weeds). The truth is that most leaf-eating caterpillars are not little green slugs. The amazing array of caterpillar colors, shapes, appendages, and behavior rivals that of their adult counterparts, and in many cases the immature organisms are far more pleasing to the eye.

Caterpillars evolved in response to a wide variety of selective pressures, but perhaps their most interesting features are adaptations against natural enemies. The value of defenses such as spines or sticky hairs, the regurgitation of plant toxins on an enemy, and the ability to mimic a snake is easy to imagine. But investigations into just how effective these defenses are—and against which enemies—reveal complex, unexpected patterns.

The vast and varied cast of characters that make their living by eating insect larval tissue includes a wide range of organisms, from microbes to primates. Two well-studied groups of caterpillar enemies are predators (many birds, wasps, ants, and true bugs) and, more obscure but no less abundant or important, parasitoids—certain wasps, flies, and nematodes whose immature stages live inside the caterpillar host, where they feed on nonessential tissues until they are ready to burst out of the devastated body and complete their life cycle as free-living organisms. Their gruesome predilection makes parasitoids great fodder for science fiction movies, but they benefit some plants by controlling populations of caterpillars.

Given the damage this sort of parasitism can cause, I expected that many defenses in the caterpillars' repertoire would have evolved in response to it. Surprisingly, however, my research, done at Tulane University with my former postdoctoral collaborator Grant Gentry, suggests this is not the case. While sticky hairs that glue an ant's mandibles together and toxic chemicals that make birds vomit can effectively deter predators, it turns out that parasitoids are actually attracted to caterpillar hosts with these attributes.

At first this finding confused us, because some of these larval defenses are formidable and have been demonstrated to affect parasitoids. Closely spaced spines, for instance, can make it harder for a parasitic wasp to lay its eggs on the caterpillar's body. And the toxins with which some caterpillars defend themselves against predators can also slow the development of, or even kill, parasitic larvae.

But we soon realized that the parasitoids' attraction to well-armed hosts makes good sense. Any parasitoid inhabiting a defenseless caterpillar becomes just as vulnerable to predators as its host is: if the larva is eaten, the parasite will be consumed right along with it. Far better, then, to parasitize a well-defended host, despite the cost. Thus, it appears that as long as caterpillars are challenged by both attackers from without and freeloaders from within, the perfect defense may elude them.

***Acharia ophelians*, a saddleback caterpillar, has stinging spines and perhaps other chemical defenses that are advertised by its bright coloration. Brush up against a group of these, and you could have a painful rash for more than a week.**

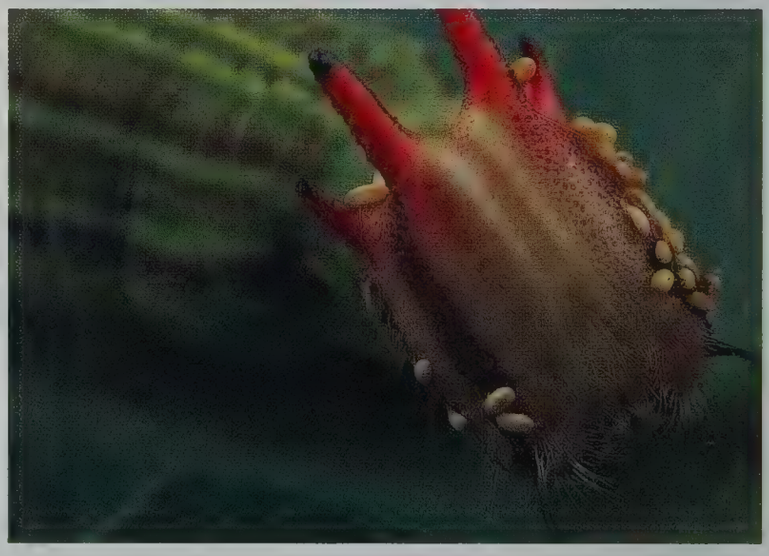
CHRIS KNIGHTS; ARDEA LONDON LTD.

A whitethroat has caught a caterpillar. From the point of view of a parasitoid that spends part of its life cycle inside a caterpillar, a species that is vulnerable to predators is not the most desirable host.

A member of the puss caterpillar family, *Megalopyge albicollis* has extremely painful stinging spines and hairs that seem to protect it even from parasitoids. The caterpillar's nickname in Costa Rica, *gusano ratón* (vermin worm), reflects the bad experiences humans have had with it.

A leafy shelter has been cut away to reveal the cocoons spun by braconid wasp parasitoids after they emerged from an *Oecophorid* caterpillar. Because they are well protected, larvae that create shelters from the leaves they feed on may be attractive hosts for parasitoids.

ELECTRONIC CATERPILLAR COLLECTIONS Insect larvae are abundant and easy to find in all terrestrial ecosystems, but they are very hard to preserve. If simply pinned, as are their adult counterparts, they shrivel and fade; when prepared with various fixatives, killing solutions, or preservatives, they often lose their bright colors and other diagnostic characters. Partly as a result of such drawbacks, good museum reference collections are almost nonexistent, and keys outlining species characteristics are unavailable for most groups. The Internet has proved an invaluable tool for circumventing these problems. Larvae can be reared to adulthood in laboratories, taxonomists can identify the adults, and electronic images of both stages can then be placed into a collection that is readily accessible via computer. Two examples of digital collections are the Dyer-Gentry databases and key, at www.caterpillars.org, and the Janzen-Hallwachs database, at janzen.sas.upenn.edu.—*L. D.*



***Opsiphanes tamarindi* cannot easily remove the tachinid fly eggs from its head. Once the eggs hatch, the larvae burrow inside the host and begin consuming nonessential tissues.**

As big as a hot dog, *Automeris*, a giant silkworm moth caterpillar, discourages some predators by its size, strong bite, and array of spines.

The hag moth larva (genus *Phobetron*) has small stinging spines and large lobes that detach when a predator grabs them. Nonetheless, it is parasitized by wasps, flies, and nematodes.

When disturbed, *Hemeroplanes ornatus* inflates and displays the underside of its front end, startling predators with its close resemblance to a pit viper. At rest, this very large caterpillar, a member of the hawk moth family (whose larvae are called hornworms), resembles a lichen-covered stick.

Face the Music

Why are we such a musical species —and does it matter?

By Susan Milius

"In our village there was a man who had a daughter, and a guy wanted to marry her," reminisces Dadie Aime Loh, from southwestern Ivory Coast. The suitor was of another religion, however. "The father said the guy must change his religion. He did. They made a song about it in the village, and everybody was singing it. They were making fun of him: 'Just to have a wife, you gave up your religion.' People back home make songs about everything."

For the Dida people, Loh asserts, music is not the same thing it is for most contemporary Westerners, and not just because the drums and bells, calls and responses, sound a different beat. Loh, who demonstrates and teaches Dida music at the University of California, Santa Barbara, conjures up a world in which gifted singers may be celebrated but the talents of a few don't silence the voices of everyone else. "If you can speak, if you can think, you can make a song," he says.

The truth is that just about everybody everywhere is musical. The most off-key croakers among us respond to music, feeling the chill in a dirge, quickening to the frolic in a reel, or waiting nervously for a twenty-foot spider to jump out of the darkness when a movie soundtrack turns jittery. Human beings appear to be musical beings—but why? Does music have a biological function? Has musicality mattered in the evolution of our species?

The first challenge faced by any theory about the origins of our musical capacity, emphasizes David Huron, head of the Cognitive and Systematic Musicology Laboratory at Ohio State University, is to explain why music is not just widespread but truly universal. Every culture that anthropologists have observed has its own music. (Music may be forbidden in some cultures at some points in their history, but repression of music is not the same as the absence of the desire to make it.) Styles of singing and types of instruments vary enormously—to the delight of fans of "world music"—but some form of music is present, often as part of important cultural traditions, from the arctic tundra to the tropical rainforests, whether for pursuing seals or for communicating with the spirits of birds.

Pervasiveness alone, of course, does not mean that a trait matters a lot in evolution. Music could be just a happy accident, notes psychologist Steven Pinker, of the Massachusetts Institute of Technology. Think about food. The vagaries of prehistoric nutrition may have favored hominids with a taste for fruit or for calorie-packed fats. Nowadays we can titillate those tastes whenever we want, but it's hard to argue that survival advantages drove humanity to evolve an enthusiasm for strawberry cheesecake. In theory, Pinker maintains, music, too, could tickle pleasure out of cognitive circuitry that evolved for more practical purposes, such as sorting out individual sounds from a noisy environment. In his 1997 book *How the Mind Works,* he writes, "I suspect that music is auditory cheesecake."

On the streets of Paris in 1935, a young accordion player puts his heart into his music.

LUDWIG
ACCORDEON

So far, that has been a hard statement to prove or disprove. But it is a view that Ian Cross, university lecturer in music at the University of Cambridge, disputes. Cross argues that dismissing music as a useless frill smacks of ethnocentricity. He concedes that the view is perhaps a fair description of "what music has become over the last hundred years within technologized and capitalistic Western society," in which a booming industry for recording and selling sounds has turned music into "a commodity to be consumed, dispensable on demand." But elsewhere in the world, people turn to music for reasons other than entertainment—from keeping workers on task to powering spiritual events.

David Huron agrees, pointing to the Mekranoti Indians in the Amazon rainforest of Brazil as an example. Mekranoti women settle down on palm leaves and sing during months-long naming ceremonies. The men typically gather to sing in the predawn hours; their singing helps keep them roused and ready for any attack. Slugabeds get roundly taunted.

Huron describes himself as open minded on the question of an evolutionary value for music. "I think we should investigate matters further before we dismiss the notion," he says. But where to look? If music is indeed a universal human trait, then clues about its functions and origin may reside in our brains. One optimist searching for brain tissue devoted to musical matters is neuropsychologist Isabelle Peretz, of the University of Montreal. Peretz has studied people

If music is indeed a universal human trait, then clues about its origin may reside in our brains.

who suffered brain injuries that shut down their musicality but left other mental faculties intact. For instance, she has tested three people who, after recovering from ruptured aneurysms, were able to speak normally and even to recognize sounds in the environment (barking dogs, cars rumbling by) but could

CHIEN-CHI CHANG; MAGNUM PHOTOS

not recognize the tunes of songs they once knew, such as Christmas carols or "Happy Birthday." One of these people said she still enjoyed music, however, and Peretz found that even though the woman couldn't recognize a tune, she was able to rate the happiness or sadness of a composition as readily as an uninjured listener could. (A different misfortune struck Russian composer Vissarion Shebalin: a severe stroke deprived him of almost all his language ability, yet he went on to compose his Fifth Symphony.)

Recently Peretz has begun to work with ten people who have no visible sign of brain injury but who describe themselves as profoundly tone deaf. Indeed, her tests have confirmed that these individuals cannot discriminate among pitches well enough to distinguish one tune from another. Such a limitation should not influence their conversation, Peretz points out, since speech, while often inflected and modulated, does not require the fine distinctions that music does. Peretz suspects, based on memoirs, that Latin American revolutionary leader Che Guevara shared their condition. Despite remarkable abilities in other areas, he remained unable to distinguish one musical piece from another—an awkward problem when it came to standing up for the national anthem.

Another intriguing line of inquiry focuses on babies' considerable responsiveness to music. Much of this research takes advantage of their tendency to react to something novel—by turning their head or body toward it—but to get bored with and stop responding to the familiar. Sandra Trehub, of the University of Toronto, for example, has found that infants can distinguish very small changes in musical patterns. Interestingly, six-month-olds react much as adults do to changes in pitch and pitch relations.

Jenny Saffran, of the University of Wisconsin–Madison, has explored babies' sense of pitch. She and her colleagues tested both adults and eight-month-olds with a series of bell tones. The infants proved far sharper than the adults at noticing sequences with the same relative pitches but different absolute pitches. Saffran proposes that people may be born with perfect pitch but lose the ability as they mature.

If such research does confirm built-in musicality, we're back to asking why. Charles Darwin addressed this question in his 1871 *Descent of Man*: "As neither the enjoyment nor the capacity of producing musical notes are faculties of the least use to man in reference to his daily habits of life, they must be ranked amongst the most mysterious with which he is endowed." Darwin suggested one answer: that music evolved as part of courtship. Initially he proposed to explain birdsong as a display, enabling a discerning female to select a mate from among a number of males. "They charm the female by vocal or instrumental music of the most varied kinds," he wrote. This process, which Darwin called sexual selection, enabled traits for the sexiest display to spread through the population. Darwin

Opposite page: Members of a Taiwanese marching band are undeterred by rain. Below: A teenage boy plays a homemade "viola" in a camp for displaced persons in Angola.

CRISPIN HUGHES; PANOS PICTURES

DAVID HURN; MAGNUM PHOTOS

Left: A young audience registers its approval at a 1964 Beatles concert in Great Britain.

JOHN VINK; MAGNUM PHOTOS

MIGUEL RIO BRANCO; MAGNUM PHOTOS

French rugby players, right, enjoy a team victory. Below: A street musician sings during *carnaval* in Brazil's eastern state of Bahia.

"Music differs clearly from other human abilities such as proving mathematical theorems, writing legal contracts, or piloting helicopters, which depend on a tiny minority of individuals being able to acquire counterintuitive skills through years of difficult training." Ultimately, Miller says, he's trying to explain why "music is so primordially sexy. A wonderful musician is just more compelling than the world's best tax accountant or a man who's assembled the world's largest ball of string."

While understanding the visceral messages of music and developing enough skill to warble a recognizable "Happy Birthday" may be easy for most people, reaching the heights of musical prowess takes time and effort and, Miller suggests, special genetic gifts. As a result, music might serve as an opportunity for sexual competition.

Ellen Dissanayake, an independent scholar in Seattle who writes on the origins of artistic elaboration (see "Birth of the Arts," December 2000/January 2001), agrees but says, "Geoffrey's argument doesn't explain enough." She finds a much stronger case for music's origins in its power to foster cooperation. The cradle of music, she argues, literally was the cradle, and then extended his idea to the origins of human music: "[I]t appears probably that the progenitors of man, either the males or females or both sexes, before acquiring the power of expressing their mutual love in articulate language, endeavoured to charm each other with musical notes and rhythm."

In recent years, evolutionary psychologist Geoffrey Miller, of the University of New Mexico, has taken a fresh look at Darwin's notion that music arose through sexual selection. If Darwin was right, music might have evolved as a display, bursting forth naturally. And, claims Miller, so it does: in human evolution, music came from the bonding duets between mothers and infants. Modern humans evolved to bear especially helpless young, compared with those of other primates, so anything that strengthened the bond between mother and infant would have had strong, immediate survival benefits and would have spread widely.

Dissanayake sees evidence for this hypothesis in the tendency of caregivers around the world to engage infants in cooing, crowing, and peekabooing interactions that display many of the components of music. In many cultures, adults playing with babies

tend to pump up the high inflections and drop the lows, so that the sounds they make take on a melodic quality. Think, for example, of simple statements such as "Look at YOU-oooo" and of many nursery games, such as the one that ends with "THIS little piggy went WEE-WEE-WEE all the way home." In addition, phrases are repeated, and adult and baby fall into rhythms.

Experiments have shown how important this timing can be. In one experiment, mothers and babies were in separate rooms but able to see and hear each other via closed-circuit television. All proceeded smoothly—mother and baby happily gazing and chirping back and forth—until the researchers manipulated the tapes so that the baby was watching a replay of an earlier reaction from its mother. When the rhythms of the mother's actions and reactions were out of sync with the baby's reactions, the baby showed signs of distress by fussing and frowning. As soon as the researchers restored real-time communication, the baby resumed gurgling and kicking its feet contentedly. The motions in such duets matter as much as the sounds, Dissanayake says.

Might music have evolved as a sexual display or from duets between mothers and infants?

Perhaps the most sweeping view of music's benefits for emerging humanity comes from Cross. He proposes that music evolved as what he calls a "play-space" for the mind. Cross offers due respect to our predecessor species, some of which had superb skills in certain domains, such as understanding inanimate materials well enough to shape them

Singing's a Hoot

Lest we humans get too smug about our standing as a musical species, consider the gibbons, our most distant living ape relatives. All twelve species sing, and in ten of them, mated pairs engage in duets. (To hear gibbons sing, go to www.gibbons.de.)

To qualify as a singer, an animal must repeat several series of notes in a recognizable temporal pattern, explains zoologist Thomas Geissmann, of the Tierärzliche Hochschule Hannover in Germany. He's analyzed singing in nonhuman primates and proposes that their "music" might have developed along an evolutionary path that human ancestors wandered down too.

M. HARVEY

Siamang gibbon

Singing evolved independently at least four times among nonhuman primates, contends Geissmann. Depending on which classification scheme is used, some twenty-six species sing. Besides gibbons, singing primates include the Madagascan lemurs called indris, the tarsiers of Sulawesi, and the titi monkeys of South America. None of these groups perch particularly close together on the primate family tree.

Geissmann proposes that the songs of all these species may have evolved from common primate vocalizations known as loud calls. Many primates, particularly adult males, belt out characteristic notes when groups meet or when something alarming happens. The singing routines of modern species are more elaborate than these calls, but there are some suggestive similarities. All songs and many calls, for example, contain runs of relatively pure notes.

Oddly enough, all the singing primates Geissmann has studied fall into the exclusive club of monogamous mammals (only 3 percent or so of all mammals tend to have one mate at a time). Whereas singing may originally have evolved in order to attract a mate or to help defend resources, Geissmann muses that duet singing in primates might have arisen along with monogamy. He imagines that a mate might have found it beneficial to repeatedly interrupt a partner's ongoing "song bout" with little phrases of his (or her) own to let potential home wreckers know that the partner was already taken. As more complex duetting evolved, singing might have strengthened pair bonds. At least in siamang gibbons, new mates have to learn the fine coordination between his part and hers.

Because our closest living relatives, the apes, give loud calls, Geissmann suspects our distant primate ancestors did too. Chimpanzees pant-hoot. Gorillas produce short bursts of notes, often while thumping their chests. Orangutans have a loud call. In fact, says Geissmann, "the only apes without loud calls are humans." Maybe these calls turned into our songs.—*S. M.*

into tools. But modern humans seem to possess a trait found in no other species—immense mental flexibility. As Cross puts it, modern humans can transfer insights from one domain to another, often to a domain that is metaphoric or symbolic. As a result, a tool is no longer just a tool. Take a knife, for example. It can slice through a slab of meat, but it can also suggest purely mental operations, such as cutting through an argument to the main point.

RHODRI JONES; PANOS PICTURES

Right: Crew members from a riverboat take a karaoke break by the Yangtze River, China. Below: To the accompaniment of a horse-head fiddle, a woman sings at dusk in Inner Mongolia.

If music played any kind of conceptual role for our ancestors, it must have deep roots in the evolution of our species. Archaeological evidence now suggests such roots. The earliest unambiguously musical object that Cross recognizes is a bone pipe found in southern Germany. (He discounts another flutelike find, from Slovenia, as being not clearly musical. Besides, he points out, it is from a Neanderthal site.) The German pipe, which was found along with other signs of modern humans, dates back to about 36,000 years ago—toward the end, Cross has written, "of the sudden efflorescence of visual art and symbolic artifacts that marks the undoubted emergence of modern human capacities."

Cross has also begun a quest for other kinds of early musical instruments. He was intrigued by stalagmite structures in some of the caves in France, Spain, and Portugal that were frequented by people some 30,000 years ago. These stalagmites—some of which show signs of ancient decorations, such as red ocher dots, as well as chipped spots and other traces of wear—ring with resonant tones when

struck. Cross proposes that ancient peoples may have "played" stalagmites like chimes. He and two archaeologist colleagues suggest that flint tools of this era might likewise have served early rock musicians. Inspired by the pleasant ringing sound that many tools make when struck, the researchers experimentally tapped a lot of rocks to get an idea of the kinds of wear marks that music-making would leave. Now Cross and his colleagues will be looking for those marks on ancient tools.

Regardless of the outcome of the rock project, the old German flute has already convinced Cross that "musicality is human and ancient"—so ancient, he says, that it could easily have played a role in that quantum leap in mental flexibility. The reason music might be an excellent promoter of mental flexibility, says Cross, is that it isn't inherently *about* anything, the way language is. Play around with language . . . *ooglu, oggli, ugly* . . . and you might be in big trouble if your word play gets overheard by someone big and cranky. Stick to instruments or meaningless sounds such as *la la la,* however, and you're safe.

EVE ARNOLD; MAGNUM PHOTOS

Looked at slightly differently, Cross observes, music can be about many things. A musician might muse about how a melody that rises and falls is like a wave breaking on a beach or a bird soaring and then diving for a fish. That's a shift from one domain to another. The melody has led the musician through a bit of cognitive acrobatics. And therein lies the value of the musical playspace: it provides opportunities to experiment with conceptual leaps while incurring little risk that anyone will spear you for doing so.

That's a difficult hypothesis to test, Cross admits. "Music leaves few traces except in the minds of those who engage in it." Of course, the agility of human thought and the ability to take one kind of idea and recast it for another domain might be just the sorts of traces he's hoping to find. "Without music," he says, "it could be that we would never have become human."

But maybe looking at how music benefits individuals is narrowing the focus too much, says Steven Brown, of the University of Texas Health Science Center at San Antonio. Like Dissanayake, Brown holds music's salient feature to be its fostering of strong bonds, although he focuses not on the mother-infant duo but on groups of people.

LENNOX MCLENDON; AP WIDE WORLD PHOTO

Rock singer Tina Turner (center) performs in Las Vegas in 1997 before a sold-out audience of more than 13,000 fans.

Singing together, dancing, even listening to the same music can help weld individuals into a team, a village, a nation. Before anybody gets too sentimental about the blessings of music, however, Brown points out that music can also transform crowds into a dangerous mob. But whatever kind of solidarity music promotes, he argues, members of such groups

Music may have helped humans acquire the immense mental flexibility unique to our species.

are more likely to survive and reproduce than are members of ragtag assemblages prone to infighting.

That train of thought assumes that evolution operates at the level of the group as well as that of the gene or the individual. The idea of group selection has been much criticized as woolly thinking in the past. Brown is not deterred, finding the evidence convincing that evolution plays favorites at many levels: "Multilevel selection is a fact of biology," he says.

One of group selection's longtime proponents, David Sloan Wilson, of Binghamton University in New York, says that he sees modern formulations of the idea increasingly invoked in studies of sex ratios and of disease virulence. "Now, *denying* the role

of group selection is beginning to appear like woolly thinking," he says.

Wilson heartily endorses Brown's assertion that group-level benefits might have driven the evolution of musicality. "I think it's entirely plausible," he says. Music strikes Wilson as a particularly promising place to look for group selection, because (unlike Geoffrey Miller) he finds the evidence for individual-level selection weak. "Music is employed in many ways that seem to benefit the whole group more than the relative fitness of the individual musician within the group," he says.

The salient feature of music may be its "groupishness," its power to function as social glue.

Brown agrees, drawing support for his hypothesis from what he calls the "groupishness" of music, especially outside Western societies. "In the rest of the world, there's not this 'I love you so much I can't live without you' stuff," he says. Instead of emphasizing individual travail, especially in romance, much of the planet's music addresses group concerns. The Aka pygmies of central Africa, for example, sing some two dozen kinds of music, each for a different occasion. Brown lists categories of songs—for hunting, for gathering, for the death of an elephant—and points out the predominance of topics that affect the welfare of the group.

ROBERT CAPA; MAGNUM PHOTOS

American soldiers and French citizens celebrate France's liberation from the Nazis, right. Opposite page: Saxophone player Bill Clinton (then President-elect) is in tune with members of the Central High School Sugar Bear Band in Macon, Georgia.

Even in Western societies, Brown finds, music often functions as social glue. In 1941 Dmitri Shostakovich composed a work, now called the Leningrad Symphony, to rally support for the city's 872-day resistance to the German siege. A live radio broadcast of the piece in 1942 was considered so important that soldiers with musical training were temporarily excused from front-line duty so they could play in the concert. A recognition of music's bonding power led Nazi occupiers in Poland and Czechoslovakia to issue a very different order—the disbanding of the national symphonies.

Solidifying membership within a group fulfills only one of music's roles, however, Brown maintains.

DAVID LONGSTREATH; AP WIDE WORLD PHOTO

Music also conveys information, with goose bumps added. It creates the visceral rush solemnifying the news that a child has reached adulthood, that a man and a woman are now one couple, that a community prays for healing. Loh offers examples from his village. "We sing when someone dies. The singing is about the life of the person, what he did bad, what was good. Also when we have a baby, there is special music, praying for him, telling him to be polite."

Catharsis is another group use of music. Brown argues that it channels grief or rage or other nearly overwhelming emotions for shared public release. Just ask people who watched the collapse of the World Trade Center towers how it felt to sing the national anthem in the following days. Most—even those who are neither religious nor nationalistic and who may be against the use of military force—are likely to say that singing with others who were going through the same experience brought some sort of relief.

Such groupish powers arise from the very structure of music, Brown maintains. "Conversation is about one person speaking and then the other," he says. "Music is about blending pitches, entraining to rhythms." If divided we fall, united we sing. □

By Harvey B. Lillywhite

TO WIPE AND WAX

IN DRY TIMES, SOME FROGS EMPLOY A CURIOUS METHOD FOR SAVING WATER.

The skin is a large and prominent organ, but we often take it for granted. While we think of our other important organs—heart, liver, kidneys, and the like—as securely placed inside us, doing complex and hidden things, we regard our skin as little more than a covering. Indeed, the principal function of skin is protective, but in various animals this role has given rise to myriad devices. Although the skin of all vertebrates has common properties, evolution has produced great variation in its shape, size, and functions and in its scales, claws, feathers, fur, spines, horns, and other appendages. Not all skin is created equal. The varied functions performed by the skin—including respiration, sensation, control of body temperature, transport of ions and water—reflect both phylogeny, or lineage, and evolutionary adaptation to a wide spectrum of different habitats.

Because amphibians were the first vertebrates to venture onto dry land, their skin has long been a subject of fascination to scientists. Amphibian skin is very different from—and, in some respects, simpler than—that of other vertebrates. It generally lacks appendages such as scales or hair and is comparatively thin and quite permeable to moisture. As a result, amphibians face an increased risk of drying out and have evolved behavioral specializations for maintaining water balance on land. In dry weather they retire to burrows, dense vegetation, or other protective places. Some amphibian species have adopted a nocturnal lifestyle to avoid

ROBERT AND LINDA MITCHELL

The orange-legged leaf frog, common to South America's dry Chaco region, is one of several frogs that secrete waxes and spread them by wiping to avoid drying out.

the drying rays of the sun; others seldom stray far from sources of moisture with which they can replenish body water after bouts of activity. Surprisingly, some of the world's driest deserts harbor one or more species of frogs or toads, though they are seldom seen except during the rainy season, when they form breeding aggregations at temporary pools. During the remainder of the year, these animals burrow into the soil and remain there in a state of dormancy, often surrounded by a protective cocoon: multiple layers of shed epidermis (the outermost skin) interspersed with layers of mucus or other secretions.

Some amphibians living above ground in arid regions are especially challenged by drying conditions and have developed some novel adaptations to conserve water. One well-known example is the South American painted belly monkey frog, *Phyllomedusa sauvagii,* which was investigated during the 1970s by Rodolfo Ruibal, Vaughan Shoemaker, and their students at the University of California, Riverside. Monkey frogs secrete waxes from spe-

cialized glands in their skin, then wipe themselves in a stereotypic manner to spread the waxes over the body. A typical wax layer produced by wiping is fifty to a hundred molecules thick—comparable to the thickness of protective waxes secreted onto the cuticle of beetles and spiders.

Reports of wiping behavior in several species of phyllomedusine frogs (members of the family Hylidae) were preceded by reports that certain African tree frogs of the genus *Chiromantis* (family Rhacophoridae) were highly resistant to drying out.

Barking tree frogs spend time at ground level (such as in water-filled pitcher plants) and in dry treetops, where waxing and wiping keep them moist.

J.H. ROBINSON; PHOTO RESEARCHERS, INC.

However, wiping itself was first noted by Charles McCann. In a 1940 issue of the *Journal of the Bombay Natural History Society,* he described the wiping behavior of *Polypedates maculatus,* a rhacophorid species known as the common Indian tree frog. During dry weather, some of these frogs took refuge in McCann's bungalow in Andheri, near Mumbai (formerly Bombay), providing him with a perfect opportunity to observe their curious mannerisms. At night they emerged from their hiding places, moved to a wet spot where they sat to absorb moisture for a while, and then ventured out in search of food. When the frogs returned in the morning, McCann witnessed each frog go through what he called "a process of 'self-massage,' a somewhat ludicrous performance." His description continues: "The head is first rubbed down from the top over the snout, by the forelegs, and then down the throat and thorax as far as the limbs will reach. This is followed by a 'massage' of the back, flanks, and abdomen, by the hind legs. The hindlimbs then massage one another. When all this 'toilet' is over, the limbs are collected under the body and the frog 'retires.'"

During the 1970s, when scientists began publishing reports on the self-waterproofing of South American phyllomedusine frogs, McCann's observations went unnoticed, as did his speculations on the purpose of wiping. "I have tried to figure out the reason for this performance," he had written, "and can only ascribe it to the possibility that the animal tries to clear its body of foreign matter adhering to its skin, perhaps also, an even coating of slime, when dry, acts as a sort of film, to prevent further evaporation of moisture." The latter interpretation turned out to be correct.

I learned about McCann's publication and became intrigued with Indian tree frogs during a visit to India roughly ten years ago, and I later returned there for a formal investigation of their wiping behavior. My collaborator, Ajay Kumar Mittal, a professor of biology at Banaras Hindu University in Varanasi, and I initially found that, like the South American *Phyllomedusa,* common Indian tree frogs could be stimulated to wipe themselves if we handled them. We next conducted some experiments in which frogs were subjected to repeated cycles of moderate but harmless dehydration before being handled. Under these conditions, the incidence of wiping increased markedly. It appeared that wiping was an adaptive response to water deprivation, but we needed to establish just how it worked.

During our investigations we uncovered an important connection between wiping and glandular secretion. As a frog wipes, the tactile stimulation of its limbs pressing against its body elicits a nerve reflex that causes muscle cells to contract around secretory glands in the skin. Wax secretions produced in these glands are thereby expelled onto the skin surface, and the frog's body becomes visibly wet. Following a bout of wiping, the frog rests motionless in a water-conserving posture—head and body low to the ground, limbs tucked tight against the body, and digits folded inward. After a few minutes the secretions dry, and the body takes on a waxy sheen. If water drips onto the back of a waxed frog, it forms beads (just as it would on a stick of butter), because the waxed skin is hydrophobic—both repelling water and retarding evaporative water loss. But if dirt or debris is dropped onto wax-coated frogs, they do not wipe it off. We surmise that grooming disrupts the integrity of the protective wax layer and is therefore detrimental to waxed frogs. Handling probably also disturbs the wax layer, which seems to explain why frogs are more likely to wipe themselves after being held.

WATER DRIPPED ONTO WAXED FROGS BEADS UP THE WAY IT WOULD ON A STICK OF BUTTER.

Both butterfat and frog wax owe their water-repellent properties to organic compounds called lipids—the key components of the water barriers present in a variety of plants, arthropods, and vertebrates. Reptiles and mammals generally lose less water through their skin than do amphibians, thanks to lipid structures within the epidermis. In these animals, lipids are deposited into spaces between cells, where they become organized into distinct sandwiched layers within the epidermis's corneous tissues (consisting primarily of fibrous keratin proteins). These sandwiched layers are also present in the skin of some birds. Although various frog species also produce lipids in their skin, either inside or outside their glands, they have only one or two layers of corneous epidermal cells—too few to provide the strong mechanical support that multiple layers supply to reptiles and mammals. Without this keratin-rich structure, the lipid layer is easily breached by movement or physical disruption. Amphibian skin thus appears to have limited options for waterproofing, because it is thin, poorly keratinized, and therefore supple. For reasons not well understood, these traits have persisted in modern amphibians, whose skin permits respiratory gas exchange while imposing the problem of water loss.

External lipid barriers spread by wiping provide a logical means of waterproofing when the skin doesn't do the job on its own. Indeed, recent studies have shown that wiping is more widespread than biologists once thought. The behavior has now been reported in several lineages of tree-dwelling frogs, from two distinct families and five continents. Our studies of the common Indian tree frog have revealed some important differences between it and the phyllomedusine frogs of South America. Wiping and waxing provide the Indian frog with only modest water resistance, so the species must also rely on behavior to avoid drying out. During hot, dry weather, the frogs hide in the sheaths of banana plants, in cracks and holes in the ground, and often in people's homes. By contrast, *Phyllomedusa*—whose skin is several hundredfold more water resistant than the Indian tree frog's—can rest in the open air on exposed branches during dry weather. It appears that differences in skin permeability are related to the glands in which the lipids are produced. In the Indian frogs, lipids are secreted from mucous glands and are therefore diluted by a mu-

HARVEY B. LILLYWHITE

Assuming nearly acrobatic postures to execute a typical waxing sequence, the orange-legged leaf frog first wipes its head, then its sides, and finally its legs and rear.

cous "carrier." In *Phyllomedusa,* on the other hand, secretions are produced in specialized lipid-producing glands that evidently contain undiluted waxes.

These varied mechanisms for secreting wax bolster the hypothesis that waxing evolved along several evolutionary pathways. Tamatha Barbeau, a former graduate student in my laboratory, discovered that six species of hylid tree frogs in Florida wipe themselves with lipids that are produced inside serous, or granular, glands. After mucous glands, these are the second most prominent type of gland in amphibian skin and are usually associated with the production of defensive compounds such as amines, peptides,

EACH FROG WENT THROUGH A SOMEWHAT LUDICROUS "SELF-MASSAGE."

and alkaloids. However, granular glands vary greatly in their structure and contents, and those of a wiping Australian hylid, *Litoria caerulea,* or White's tree frog, also have been shown to contain lipids. Perhaps the lipid-producing glands of modern South American phyllomedusine frogs evolved from the granular glands of their hylid ancestors.

One could also speculate that in some lineages, wiping evolved first as a means of stimulating secretions (either purely mucous or granular). By itself, mucus helps keep skin moist. The American bullfrog, for example, discharges copious amounts of mucus when basking in the drying rays of the sun. Water evaporates from the film of mucus, protecting the underlying skin from dehydration, though only as long as the body water lost to evaporation can be replenished, say from wet soil, a stream, or a pond's edge. Perhaps some of today's waxing and wiping frogs had similar mucus-secreting ancestors.

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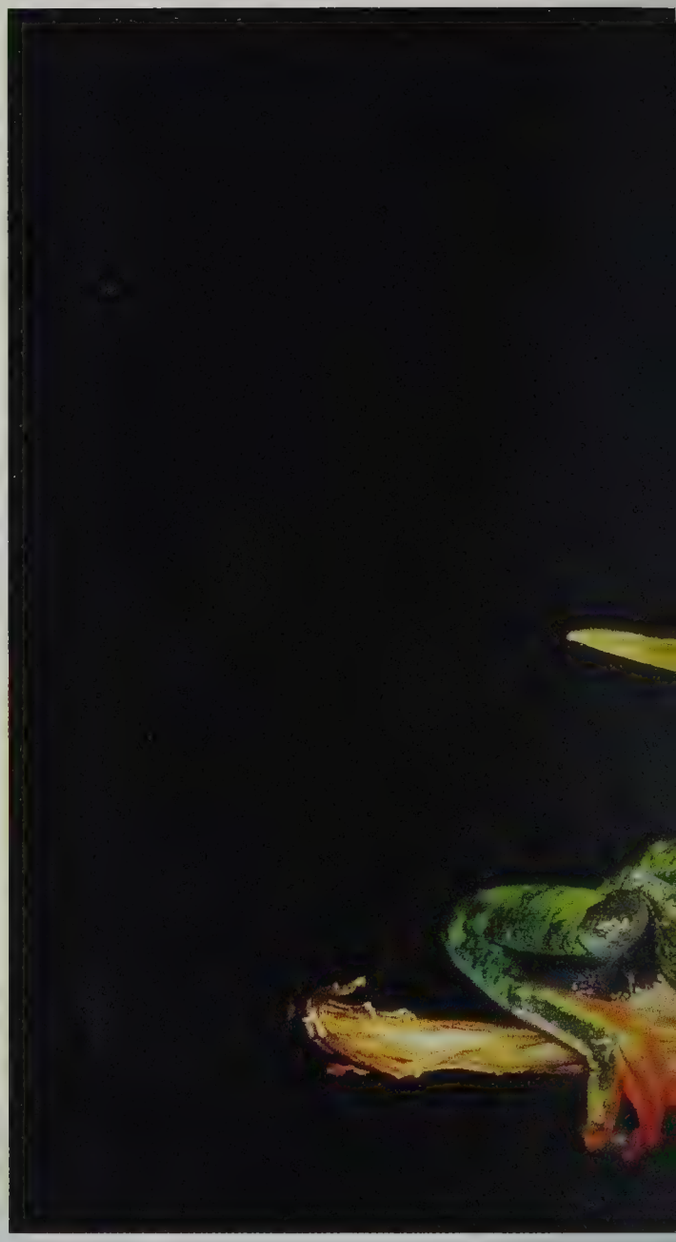
The painted belly monkey frog of South America, above, wipes its skin with wax from specialized lipid glands. The common Indian tree frog, right, secretes mucus along with the waxes and must adopt a water-conserving crouch after wiping.



As these ancestral frogs progressively invaded drier habitats, the evolution of a lipid film from a mucous film would have prevented the drying-out of both the underlying skin and the entire animal when water was scarce or absent.

All species of frogs thus far known to wipe themselves with secreted lipids reside in trees or in shrubbery and also have a geographic distribution that includes arid or semiarid environments. The Indian tree frog *Polypedates maculatus* is widely distributed throughout India but absent from rainforests, while a closely related sister species, *P. leucomystax,* the common Southeast Asian tree frog, lives exclusively in the moist rainforests of India and avoids dry places. Preliminary observations suggest that the latter species neither secretes lipids nor wipes itself. The secretion of lipids and the wiping behavior of the common Indian tree frog therefore appear to be linked to survival in comparatively dry regions.

DAVID LIEBMAN

One of a pair of red-eyed tree frogs from Central America wipes its face, a behavior shared with several other species of the family Hylidae.

Many dry, low-latitude habitats experience high temperatures, so overheating can also be a problem for tree frogs. Several species of frogs, including the tree frogs that engage in wiping, sweat in response to increasing body temperature. The sweat secretion, which is largely mucus and water, cools the skin by evaporation, much like human sweat. So, in the case of the Indian tree frog, mucous secretions are used in two different ways: at higher body temperatures they provide water for evaporation, while at lower temperatures they deliver lipids to the skin for waterproofing. This species begins to sweat at a body temperature of about 86° F, whereas the more waterproof painted belly monkey frog does not sweat until its body temperature reaches 102–104° F. In both species, once a lipid barrier is established by wiping, the mucous glands don't discharge their contents unless the body temperature exceeds the threshold for sweating. By tolerating higher body temperatures, the monkey frog—with an intact lipid barrier on its skin—can better withstand exposure to hot, dry weather without risk of glandular water loss.

Amphibians are regarded as sentinel vertebrates in the current drama of global extinctions. Environment-induced stresses appear to pose particular risks to them, partly due to the sensitive nature of their skin. Wiping and waxing adaptations are extraordinary biological phenomena that integrate behavior with biochemistry, physiology, and ecology. We know very little about the origins of wiping and waxing or how rapidly these behaviors might evolve. Nevertheless, they are likely to play some role in the overall repertoire of important adjustments that amphibians will need to make in response to the localized droughts and temperature changes predicted to result from global climate change. □

JEAN-PAUL FERRERO; AUSCAPE

The flightless kagu, right, which lives only on the South Pacific island of New Caledonia, is the closest living relative of the sun bittern, opposite, of Central and South American rainforests.

MICHAEL & PATRICIA FOGDEN

GONDWANA GENESIS

A combination of molecular data, anatomical evidence, and knowledge of ancient geography is providing new answers to the contentious issue of when—and where—modern birds arose.

By Joel Cracraft

About 65 million years ago a giant asteroid, perhaps six miles in diameter, tore through Earth's atmosphere and slammed into the Gulf of Mexico, carving a crater nearly a hundred miles in diameter. The impact released billions of megatons of energy. Smoke and dust from the ensuing firestorms cast a sooty blanket over much of Earth, blocking sunlight and widely disrupting terrestrial and marine ecosystems. With this cataclysm came the mass extinction event that marks the boundary between the Cretaceous and Tertiary Periods—the K-T, as it is called by geologists.

The K-T mass extinction has captured our imagination because of claims that it brought about the end of the dinosaurs. Yet as most people know, the descendants of dinosaurs—birds—survived and are with us today. The common ancestor of modern birds, which are known technically as Neornithes, and of bipedal maniraptoran dinosaurs (think *Velociraptor*) lived sometime during the Jurassic, more than

150 million years ago. Many lineages of premodern birds subsequently branched off the avian tree, including one of the most famous and important fossils, *Archaeopteryx,* recovered from the Upper Jurassic Solenhofen limestone quarries of Bavaria. After *Archaeopteryx,* numerous Cretaceous forms evolved. These were less advanced anatomically than modern birds, and all are now extinct. As far as we know, none survived the K-T asteroid event.

Although most of the attention given to bird evolution has focused on birds' relationships to dinosaurs, crucial questions about the origin and early evolution of modern birds have largely gone unanswered. When and where did they arise? How and when did they diversify and spread around the world? And what influence, if any, did the K-T mass extinction have on their history?

In recent years, ornithologists have sought to investigate these questions using very different kinds of evidence. Taking a traditional approach, some pa-

Both the sun bittern and the kagu are quick to spread their wings in threat displays. The sun bittern above is defending its nest by a stream in Costa Rica.

JEAN-PAUL FERRERO; AUSCAPE

BIOS (A. COMPOST); PETER ARNOLD, INC.

Ratites—big, flightless ground birds including the emu, rhea, ostrich, and cassowary—are true Southern Hemisphere specialties. Above: An emu with chicks forages in Australia's Northern Territory. Right: Marked by a horny head ornament called a casque and by particularly lethal clawed toes, the cassowary inhabits forests of New Guinea and northern Australia.

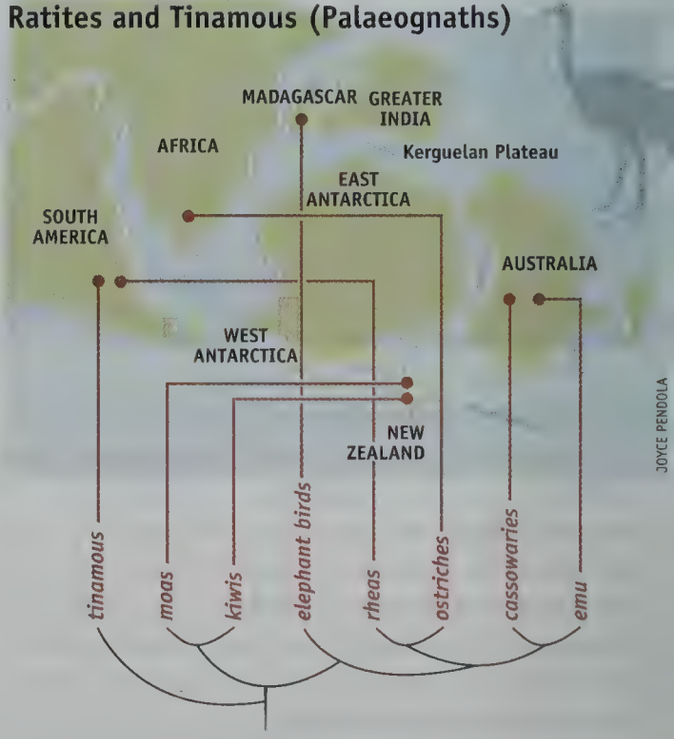
leontologists point to the virtual absence of modern birds in the Late Cretaceous and their abundance in the Early Tertiary in North America and Europe. From this they conclude that the evolutionary history of modern birds began in the Northern Hemisphere after the K-T extinction event.

A contrasting view of modern bird beginnings comes from the expanding science of molecular systematics, which uses comparative DNA data to illuminate genealogical relationships. By correlating the amount of genetic difference between pairs of species with their presumed time of divergence from each other based on fossil evidence, some scientists believe they can calibrate a molecular "clock." The clock allows them to date the divergence of species pairs having no fossil record: the greater the difference in DNA sequence between two organisms, the farther back in time their evolutionary separation is thought to have occurred.

Many lineages of modern birds existed prior to, and therefore must have survived, the K-T extinction event.

Several studies have independently examined sequence differences for a handful of genes in a small number of bird groups. The various investigators calibrated their clocks using different fossils and somewhat different methods of analysis, yet each concluded that these groups are so different genetically that they must have diverged sometime in the Cretaceous—that is, before the asteroid hit. According to this view, the pattern of the fossil record is biased: the large Tertiary record of birds exists only because sediments of that age are abundant

Ratites and Tinamous (Palaeognaths)



JOYCE PENDOLA

compared with those of the Cretaceous, and the fossils are found mostly in the Northern Hemisphere because that's where paleontologists do most of their work.

Such scientific debates are often frustrating because they are unlikely to be resolved easily. Each side is relying primarily on one kind of evidence (here, either fossils or molecules), and too much time is spent dismissing the views of the opposing side. One way out of the conundrum is to obtain yet another kind of evidence and see how it fits together with the other data.

Research in my laboratory at the American Museum of Natural History has done just that. Employing new data—both molecular and anatomical—we have attempted to reconstruct the genealogy of modern birds and to use those findings to understand their past geographical distributions. This method of mapping reveals that many groups of modern birds were widely distributed on the ancient Southern Hemisphere supercontinent known as Gondwana and that they attained their present-day distributions as that landmass rifted and drifted during the Cretaceous and Early Tertiary. Combining knowledge about the breakup of Earth's early landmasses with our understanding of avian relationships and the fossil record, we have concluded that many lineages of modern birds existed prior to, and therefore survived, the K-T mass extinction event, thus supporting the conclusion derived from molecular clocks.

To understand this story, it helps to envision how Earth's landmasses fit together in the Early to mid-Cretaceous, about 120 to 100 million years ago. North America, Europe, and Asia formed a large supercontinent called Laurasia. Far to the south, Gondwana was beginning to separate into the continents we recognize today. The South Atlantic Ocean was forming and was continuous with another newly created ocean that extended eastward around the southern and eastern coasts of Africa. Yet Africa and South America maintained a connection across their midsections and probably did so until about 100 to 105 million years ago.

DES BARTLETT; BRUCE COLEMAN, INC.

The largest of the world's birds, ostriches speed across their present African habitat.

The heart of Gondwana was Antarctica, composed of two distinct geological sections: massive East Antarctica and long, narrow, mountainous West Antarctica. Southern Africa was merged with the margin of East Antarctica until they drifted apart about 140 million years ago. A combined continent of Madagascar and India was also sutured to East Antarctica, and farther east still was Australia. Southern South America had a connection across East Antarctica to Australia, and the rising Andean mountains had a nearly linear connection across West Antarctica to the continental block of proto-New Zealand and lands to the north, including the Norfolk Ridge and New Caledonia. A period of global warmth and moisture prevailed, and tropical or subtropical vegetation covered much of Gondwana. It was a favorable time for the dawn of modern birds.

For more than two decades a few ornithologists, including me, have proposed that various lineages of modern birds were distributed across Gondwana at the time of continental breakup. But today a clearer understanding of the very early history of modern birds allows us to pose an even bolder hypothesis: birds not only inhabited Gondwana from an early date, they originated there.

The strongest case for this conclusion emerges when we examine the earliest modern birds, which can be divided into three major lineages. First are

the palaeognaths, or "old jaw" birds, so called because they share a particular configuration of bones in their palate. Palaeognaths include tinamous—small, chickenlike birds of tropical America that are capable of flight—and ratites, large flightless birds such as the ostriches of Africa, rheas of South America, emus and cassowaries of Australia, kiwis and extinct moas of New Zealand, and the extinct elephant birds of Madagascar.

All remaining birds are termed neognaths ("new jaws") and are subdivided into the other two major lineages of modern birds. One of these is the Galloanserae, including the galliform birds (chickens, pheasants, the curassows and guans of tropical America, and the megapodes, or mound builders, of Australasia) and their close relatives, the anseriforms (ducks, geese, swans). All other birds, from loons and penguins to woodpeckers and sparrows, are placed together in the third main lineage, the Neoaves.

When the evolutionary trees of these birds are plotted on a map of Cretaceous Earth, their Gondwanan distributions become apparent. Thus, within the palaeognaths, tinamous are in South America, kiwis and moas extend across West Antarctica to New Zealand, and emus and cassowaries span East Antarctica to Australia. Moreover, if ostriches and rheas are indeed related to each other, as some evidence seems to suggest, then they represent a historical connection across the South Atlantic between Africa and South America. The Galloanserae have similar trans-Antarctic distributions. The most primitive relatives of chickens and pheasants are the megapodes in Australasia and the guans and curassows in tropical America; likewise, two of the most

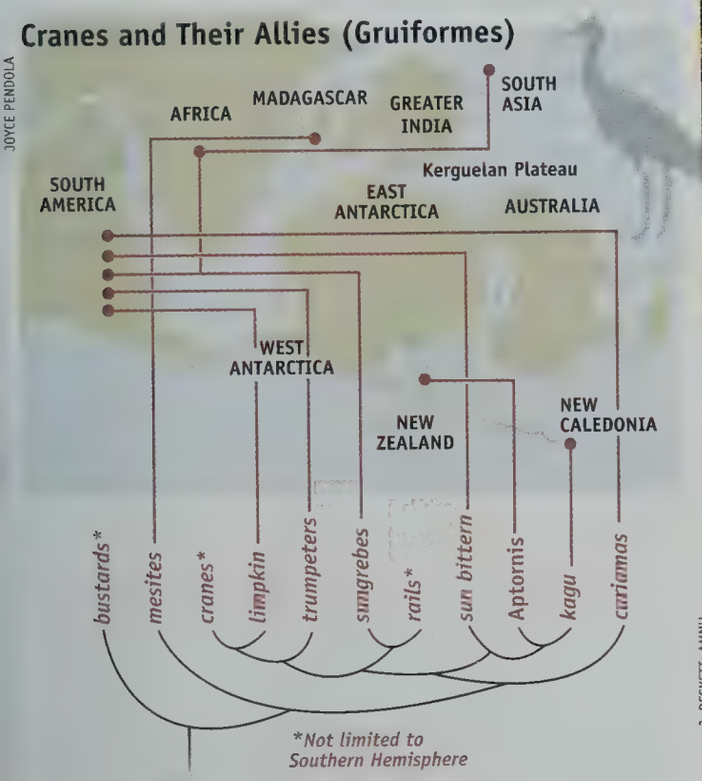
The most primitive relatives of chickens and pheasants live in Australasia and tropical America.

JEAN-PAUL FERRERO; AUSCAPE

A venerable line: Australia's magpie goose, below, belongs to one of the most ancient lineages of the anseriforms, the avian group that encompasses all ducks, geese, and swans.

ancient lineages of the anseriform birds, the screamers and the magpie goose, are found in South America and Australia, respectively.

As I will shortly describe, the third great basal lineage—the Neoaves—also shows Gondwanan roots. If we combine this with the fact that all members of the Neoaves branched off the avian tree later than the palaeognaths and Galloanserae, we must conclude that even these advanced birds are older than some paleontologists have thought.



Perhaps the most spectacular example of a trans-Antarctic distribution pattern within the Neoaves involves a medium-sized flightless bird—the kagu—that inhabits the remote island of New Caledonia in the southwestern Pacific. The kagu has long been classified with the gruiform birds, a grab bag of anatomically diverse families such as the familiar cranes and rails. Thanks to the detailed anatomical work of Bradley Livezey, a curator at the Carnegie Museum of Natural History in Pittsburgh, we now have strong evidence that most of these groups are indeed related. Livezey's findings, moreover, confirm a conclusion that I came to nearly fifteen years ago, also based on anatomical similarities—namely, that the closest living relative of the kagu is the sun bittern, an inhabitant of rainforests of Central and South America, half a world distant from New Caledonia. Comparisons of DNA sequences in our laboratory strengthen the evidence for this remarkable relationship.

JOHN CANCALOSI; PETER ARNOLD, INC.

J. BECKETT; AMNH

The malleefowl, above, builds nest mounds of sand and vegetation, which serve as temperature-controlled incubators for its eggs. Left: A reconstruction of *Aptornis*, a flightless New Zealand bird that went extinct after the islands were first settled by humans some 1,200 years ago.

How do two birds, one flightless and one barely capable of flight, evolve a distribution pattern like this? The answer can be found by deducing where their common ancestor was living 85 million years ago. Prior to that time, the southern continental blocks fit together in such a way that we could draw

J. BECKETT; AMNH

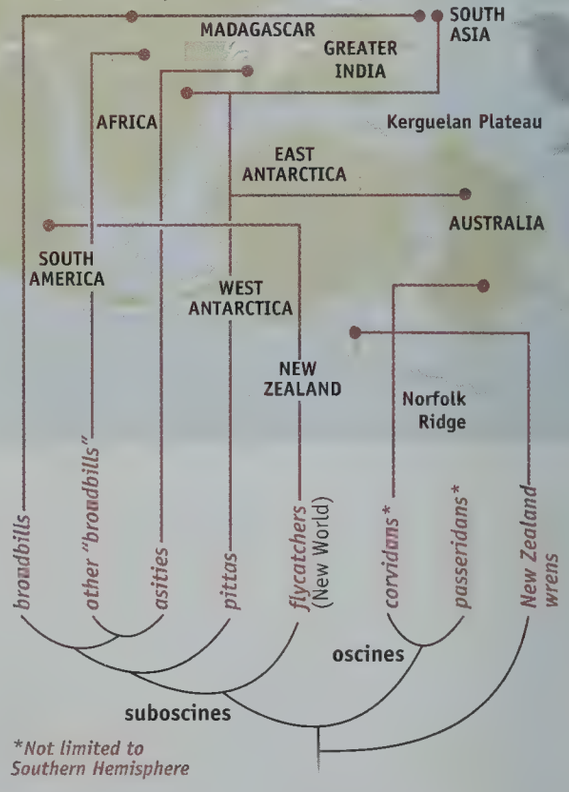
Molecular evidence has shown that the extinct Stephens Island wren, above, along with three extant species of enigmatic New Zealand wrens, are the oldest of all passerines, or perching birds.

a near-straight line from South America, across West Antarctica, onto the New Zealand landmass, and then northward along the now submerged Norfolk Ridge to New Caledonia. The kagu–sun bittern ancestor would have had no need to fly to what is now a remote island. It could have walked.

This scenario is further strengthened by another neat bit of information. Although the closest *living* relative of the kagu is the sun bittern, the kagu's actual closest relatives are two large, now extinct New Zealand species classified in the genus *Aptornis*. A finding such as this is the greatest thing since sliced bread to a biogeographer like me, but the story gets even better: both species of *Aptornis* were flightless. Like the unfortunate moas, with whom they shared the New Zealand forests, the two species of *Aptornis* were killed off for culinary purposes by the Polynesians sometime after these seafarers arrived on the islands, around A.D. 750–900. Thus, if two close relatives (in this case, *Aptornis* and the kagu) are flightless, then the simplest hypothesis is that their common ancestor was also flightless. Add to this the fact that the sun bittern is a very poor flyer, and we can see that species in this lineage were not well suited for crossing open oceans. This historical scenario is made more compelling by recent geological evidence that the Norfolk Ridge, which except for Norfolk Island runs submerged between New Zealand and New Caledonia, is itself continental crust and was exposed and covered with forest during at least part of the Late Cretaceous and Early Tertiary.

Other gruiforms are also distributed on former pieces of Gondwana. There are trumpeters, cariamas, and the limpkin in South America; sungrebes in South America, Africa, and southeastern Asia; and mesites on Madagascar. Mesites, small terrestrial birds with poor powers of flight, are especially noteworthy because they are one of the very oldest branches of the gruiform tree. How and when they arrived on Madagascar has always been something of a mystery, but I will propose a new answer to this puzzle after we've looked at another group of Neoaves—the Passeriformes, or passerines—which also appear to tell us something important about the history of Madagascar and the other southern continents.

Perching Birds (Passeriformes)



JOYCE PENDOLA

Passerines, or perching birds, are a hugely diverse group encompassing 60 percent of all living bird species. Ornithologists subdivide these 6,000 or so species into two large assemblages, based on anatomical differences in their syrinx—a vocal organ of muscle and cartilage located along the windpipe, or trachea. The suboscines have a rela-

tively simple syrinx, whereas the oscines (the songbirds) have a more complex structure and, in general, a more elaborate vocal repertoire. More pertinent to this discussion, both groups apparently originated in Gondwana.

Suboscines, which include flycatchers, antbirds, woodcreepers, and ovenbirds, are now diverse in the New World, with about 1,100 species, nearly all of them in South America. The Old World has only about 50 species of suboscines, and these fall into three small groups: the outrageously colorful, short-legged, plump pittas; the broadbills; and the asities. Pittas and broadbills are found primarily in southern and southeastern Asia, but a small number of species from both groups are found in Africa, and two species of pittas have reached Australia from the north. The asities are the peculiar ones. Restricted to Madagascar, the four species—with their short, sharp bills—look nothing like broadbills. However, Richard Prum, an ornithologist at the University of Kansas, examined their anatomy and proposed that asities are simply modified broadbills. The exact relationship between broadbills and asities is still an open question, but there seems little doubt that the two groups are related to each other and to pittas. All of these suboscines—both Old World and New—thus have geographical distributions that point back to Gondwana, and their beginnings there make even more sense once their close relatives, the songbirds, are taken into account.

Both Old and New World suboscines have geographical distributions that point back to Gondwana.

The evolutionary history of the songbirds is still incompletely understood, but current thinking holds that there are two major groups with complex interrelationships. One of these lineages, called the Corvida, contains all the crowlike birds, including crows and a large number of distinctive Australian groups, such as honeyeaters, bowerbirds, lyrebirds, and my own favorites, the splendidly adorned birds of paradise. DNA sequences determined in our laboratory show that all the most primitive corvidans are indeed Australian and that they diversified long ago, thus firmly anchoring the origins of the entire lineage in Gondwana.

The other main branch of the songbirds, called the Passerida, is hugely diverse; among its nearly 3,500 species are counted the finches, sparrows, thrushes, warblers, blackbirds, tanagers, and many others. Passeridans are distributed nearly worldwide. The current view is that they arose in the Northern Hemisphere and later dispersed to South America, Africa, and Australasia. This idea will have to be modified, however, because of new molecular evidence developed independently by Keith Barker, a postdoctoral fellow in our laboratory, and by my own research group. Some of the very primitive lineages assigned to the corvidans, we have learned, are actually more closely related to passeridans. This means the passeridans also had their beginnings on Gondwana.

These new findings raise the question of how the ancestors of the Northern Hemisphere passeridans reached there in the first place. Given our current state of knowledge, any answer to that question is going to be speculative, but it has to do with passeridans being related to corvidans as well as, somewhat more distantly, to the suboscines, which are all Gondwanan. And to seal matters, there are the enigmatic New Zealand wrens, which I have conveniently ignored until now. These tiny little birds, with short tails and sharply pointed bills, include only three species. (A fourth, the Stephens Island wren, was apparently exterminated by a lighthouse keeper's cat at the end of the nineteenth century.) Molecular sequencing results from both our lab and that of George Barrowclough, my fellow curator at the American Museum of Natural History, indicate the New Zealand wrens are at the very base of the passerine tree. Clearly these birds

JOHN S. DUNNING; PHOTO RESEARCHERS, INC.

Representing the New World suboscines: A dot-backed antbird perches in the Peruvian understory. Antbirds of various species are known for their habit of following columns of ants through tropical forests.

are very old inhabitants of New Zealand and provide another bit of evidence that the whole passerine group arose in Gondwana.

Now the story is at a point where the loose ends can be tied up—I hope—into a neat general hypothesis that explains why birds are distributed as they are and that resolves, at least partially, the debate over when the modern birds evolved. The many trans-Antarctic distribution patterns I have described for palaeognaths, Galloanserae, gruiforms, and passerines—and other groups such as parrots as well as swifts, hummingbirds, and their relatives the owls and the nightjars—strongly indicate that Gondwana harbored a diverse bird fauna. We can infer minimum ages for some of these lineages by correlating the time they were presumably isolated on fragments of Gondwana with the time of continental drift. New Zealand drifted north from West Antarctica beginning about 85 million years ago, which implies that kiwis, moas, the common ancestor of *Aptornis* and the kagu, and the New Zealand wrens as well are at least that old and that their lineages were in existence about 20 million years before the K-T extinction event. Likewise, if rheas and ostriches share a common ancestor, then the separation time of Africa and South America indicates that those birds have been evolving apart for 100–105 million years.

Trans-Antarctic distribution patterns indicate that ancient Gondwana harbored a diverse bird fauna.

KEVIN SCHAFER; PETER ARNOLD, INC.

Southeastern Asia is home to the majority of Old World suboscines, including the blue-winged pitta, below, and the lesser green broadbill, opposite page. Broadbills are related to another group, the asities, which are found only on Madagascar.

And what about Madagascar? That island continent drifted from Africa and moved south and east beginning about 165 million years ago, far too early for any group of modern birds to have gone along for the ride. Yet Madagascar had another connection with the rest of the world: Until 84 million years ago, Madagascar and the Seychelles Islands were connected to what geologists call Greater India, a continental block nearly twice the size of peninsular India today (Greater India drifted north and collided with Asia about 65 million years ago). This Madagascar–Seychelles–India megacontinent was once joined to East Antarctica, and for a time after they began separating, a land connection was apparently maintained via the Kerguelan Plateau, a large volcanic platform that formed 110 to 115 million years ago (only Kerguelan Island is now above water). Dredging from the top of this platform has revealed that a tropical forest once existed there, and no doubt it extended across much of Madagascar and Greater India. Late Cretaceous fossils of dinosaurs, crocodiles, and other vertebrates on Madagascar, nearly all of which have affinities to groups in India and South America, suggest that a land connection to Antarctica existed perhaps as recently as 85 to 95 million years ago. That seems late enough to explain the presence of elephant birds, mesites, and asities on Madagascar and perhaps—and I confess this is bald speculation—late enough for India to have carried the ancestors of the songbirds (and who knows what else) northward to dump them on the shores of Asia in the Early Tertiary.

Finally, many of the early lineages of modern birds may have escaped the K-T asteroid calamity because they were to be found mainly on Gondwana. Over the past decade, geologists have accumulated evidence that terrestrial ecosystems on the southern continents were not as badly disrupted, or subject to as much extinction, as were their Northern Hemisphere counterparts. All of this goes a long way toward explaining why modern birds appear to be so old (as suggested by the molecular evidence) and why they were not present in the Laurasian fossil record until the Tertiary.

Is this storytelling? Not really. Ornithologists can get out in the field and dig up fossils, hunker down over a microscope to understand bird anatomy better, or work in the lab and sequence more DNA. All of their new evidence can be used to test and refine—or reject—these scenarios. But one thing seems to be emerging from recent studies: relatives of our backyard feathered friends are older than many of us previously suspected, and they were flying—and walking—around on the ancient southern supercontinent of Gondwana. □

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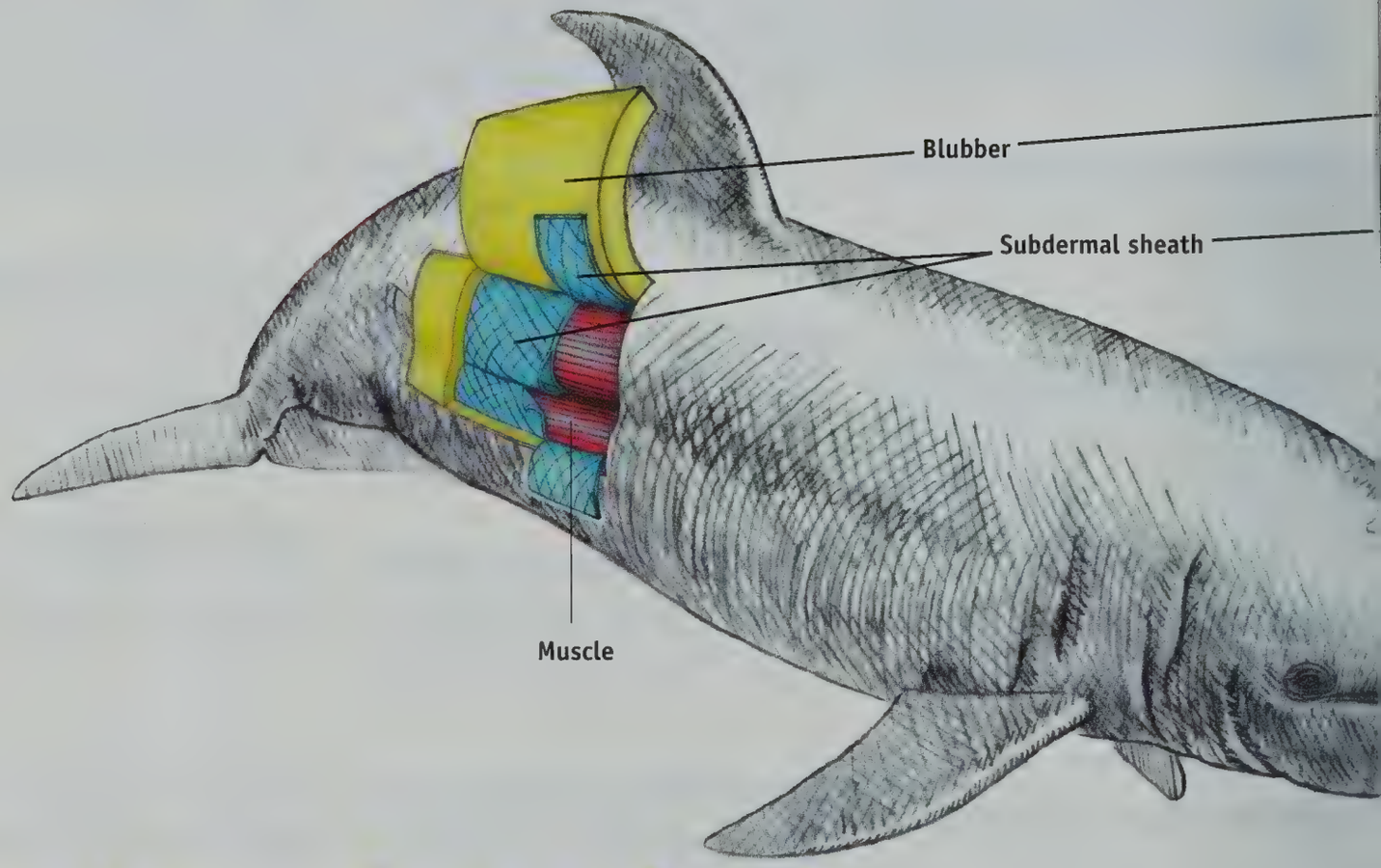
BIOMECHANICS



Spring-Loaded

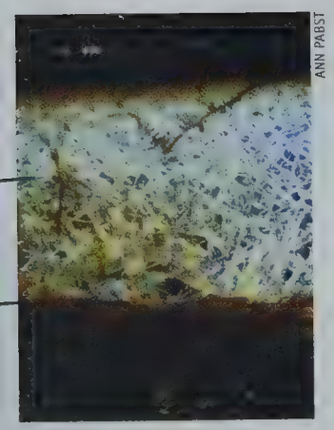
Every beat of a dolphin's tail stores elastic energy that helps propel the animal forward.

Story by Adam Summers ~ Illustrations by Sally J. Bensusen

The two Pacific white-sided dolphins riding the bow wave of our boat are a paean to power and a testament to biomechanical efficiency. Though the boat motors along at eighteen knots, the dolphins keep pace without visible effort, their tail flukes barely beating in the clear blue water. When they slide off the wave, moving away from the boat, they increase their pace to an easy lope more akin to the stride of a long-distance runner than that of a sprinter. Besides symbolizing grace, speed, and exuberance, dolphins are a wonderful aquatic example of an important principle of locomotion: the temporary storage of energy in a spring.

To experience the benefits of spring-loaded locomotion, just hop on one of the icons of 1950s popular culture, a pogo stick. The downward part of each bounce compresses a spring at the bottom of the stick; energy stored there is then converted into the upward thrust of the next bounce. To bounce higher (or farther), all you have to do is push down a little harder on the spring; a small investment of energy produces a significant increase in jumping power. Kangaroos capitalize on this principle when they hop.

A clue that dolphins (and probably many other cetaceans) use biological springs to store energy lies in data collected by Terrie Williams, of the University of California, Santa Cruz. She trained bottlenose dolphins to swim in place against a stationary target designed to register the force with which they were pushing. The

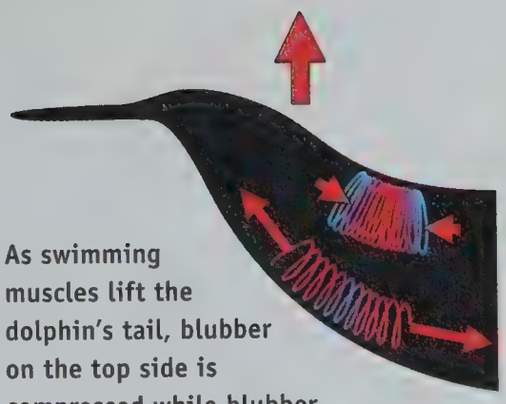


The subdermal sheath attaches some of the dolphin's muscles to its skeleton and provides some of the "spring" in the animal's movements.

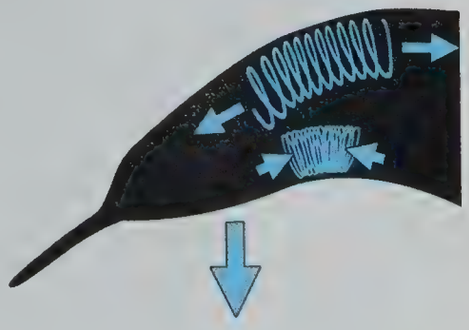
faster they beat their tails, the harder they pushed (and the faster they would have swum if they had been unrestrained). Responding to signals, the dolphins willingly maintained several different tail-beat frequencies, even though all that churning got them nowhere. Meanwhile, Williams measured how much oxygen the animals consumed while generating the force, since oxygen consumption is an indication of energy used. She found that even when the dolphins nearly doubled the force they were producing, their metabolic rate—as well as the frequency with which they popped above the surface to breathe—did not change.

The biomechanics of marine mammals, and particularly how they store elastic energy, is the subject of research in the lab of Ann Pabst and William McLellan at the University of North Carolina at Wilmington. Much of their work focuses on the animals' hind end, which in whales and dolphins tapers to a narrow tailstock that is higher than it is wide. The tailstock ends in the flukes; locomotion is powered by the up-and-down motion of these broad, flattened, propulsive blades. Muscles contract to pull the tail up, but at some point the tail must stop, reverse direction, and go down again. This reversal could be accomplished actively, through the contraction of opposing muscles, or passively, by the action of springs.

Pabst and McLellan's studies have led them to speculate that blubber and a connective tissue called the subdermal sheath are the springs in the dolphin's pogo stick. A stiff, helically wound membrane, the subdermal sheath surrounds the entire tailstock and attaches some of the underlying muscles to the skeleton. When the tail is on its way up, the sheath on the bottom side of the tail is stretched, storing some energy for the downstroke. On the way down, energy gets stored on the tail's top side. Perhaps even more important is the role of the blubber, a thick layer of fat that lies beneath the skin and, unlike the fat of your next-door neighbor's beer belly, is reinforced with a highly organized, three-dimensional weave of collagen fibers. This fibrous material gives dolphin blubber a stiffness and resilience not found in other forms of fat. Specialized triangular wedges of blubber run along both the top and the bottom of the tailstock. When a swimming dolphin flips its tail up, the top wedge compresses and the bottom wedge stretches. Once the tail can go no higher, the wedge of blubber on the top pushes it (and the wedge on the bottom pulls it) back down.



As swimming muscles lift the dolphin's tail, blubber on the top side is compressed while blubber and the fibers of the subdermal sheath on the bottom are stretched, storing energy for the downstroke.



As the muscles relax, the previously compressed blubber springs back and may help push the tail down. The now compressed blubber and sheath on the tail's underside may also contribute to the downward pull on the tail.

The combination of these two biological springs—the blubber and the sheath—may be what helps propel the dolphin at speeds greater than twenty miles per hour, making them the envy of swimmers and engineers alike. Perhaps our Olympians are on the wrong track, losing body fat to go faster. The trick might be to acquire better-designed fat, not less of it.

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THE NATURAL MOMENT

Saline Away

Photographer Mike Parry was taking a break between dives in shallow water off New Britain Island in Papua New Guinea when he saw a log floating close to his boat. A guide set him straight: that was no log, that was a saltwater crocodile. Would it be safe, Parry wondered, to get closer? His was no idle rumination—the saltwater crocodile, *Crocodylus porosus* (called a "salty" in Australia), has been known to include *Homo sapiens* in its diet.

The largest living reptile (males can grow to twenty-three feet long, females to ten), *C. porosus* is found throughout the tropical regions of Asia and the Pacific. Although the species is still threatened by the loss of its freshwater breeding habitat, conservation and breeding programs have reduced the pressures brought to bear on it by hide hunters.

All crocodiles are equipped with modified salivary glands that allow them to tolerate saline water; it's no surprise, then, that *C. porosus* can wander several hundred miles from shore with no trouble. For most individual animals, though, seafaring is more forced than elective. Adults hog good breeding territory in freshwater swamps and near coastlines, pushing younger and weaker animals to saltier regions. Unable to establish their own territory, the castaways—perhaps like the young salty that Parry spotted—often strike out in search of hospitable river systems.

Quickly shoving on fins, mask, and snorkel, the photographer grabbed his camera, slipped overboard, and swam to within a few feet of the crocodile. He remembers the mesmerizing stirring of its tail, the blue of the semitransparent membrane covering its eyes. The crocodile dived to the grassy seafloor. Parry followed and was able to take a few shots before the animal disappeared.

Photograph by
Mike Parry MINDEN PICTURES

REVIEW

Reading the Heavens

By George Saliba

Astrology—an amalgam of myth, mathematics, philosophy, and astronomy—has mirrored social history through the ages.

Scarcely a culture, ancient or modern, has not produced people who have wondered at one time or another about the order of the universe in which we live and the likely laws that govern it. Their answers often range from pure myth, fantasy, and free association to supposedly universally testable rules that can account for the natural phenomena we all observe. The case of astrology is of special importance because it speaks to the basic human anxiety about the order of the universe and purports to endow its practitioners with the power to predict a person's character and destiny from the arrangement of the planets at the specific moment of birth. This kind of speculation goes back to the earliest texts of ancient civilizations, such as those of Mesopotamia, Egypt, India, and China. A glance at modern magazines will convince anyone who needs convincing that such astrological speculations persist right up to the present.

Sumptuously illustrated with reproductions of manuscript pages from volumes still found in collections of rare books, *Astrology: A History* covers the field's documented beginnings in Babylonia, its assignment to the celestial sphere during Greek and Roman times, its diffusion and adaptation in India, China, and the Middle East, its eclipse and reemergence in Western Europe during the Middle Ages, its revival during the Renaissance, and its increasing marginalization as the pure sciences became more widespread and accepted.

SCALA/ART RESOURCE, N.Y.

A page from a twelfth-century work authored by Hildegard of Bingen depicts man as the focus of celestial forces—the basic tenet of astrology.

Astrology: A History, *by Peter Whitfield (Abrams, 2001; $35)*

Peter Whitfield, an authority on maps and the author of a number of books on different aspects of the history of ideas, touches on some of astrology's great proponents: Greek philosopher Aristotle, Alexandrian astronomer Ptolemy, Islamic astrologer Abu Ma'shar, medieval philosopher Albertus Magnus, Elizabethan cosmologist and astronomer John Dee. In elaborating how astrology has permeated social and intellectual history, Whitfield looks at the astrological subtext of Chaucer's *Canterbury Tales,* for example, as well as Shakespeare's seven-ages-of-man soliloquy in *As You Like It.* He describes the Zodiac Man—each of the zodiac's twelve signs was thought to influence a different part of the body (a concept first described in Latin poet Marcus Manilius's first century A.D. *Astronomicon*)—and discusses the development of astrological medicine. Whitfield also explains the astrolabe, a two-dimensional model of the heavens that allowed an astrologer to determine, for any required date, the position of the ascendant zodiac sign.

A reader who is interested in the subject but not necessarily ready to roll up his or her sleeves and start delving into the technical details of astrology can peruse this book with pleasure. For an in-depth history of the subject, one would do better to dust off the century-old volumes of Auguste Bouché-Leclercq, *Les Précurseurs de l'Astrologie Grecque* (1897) and *L'Astrologie Grecque* (1899), which are not mentioned in Whitfield's bibliographical note at the

end of the book. To read Leclercq's great works, one has to have the patience to cover close to a thousand pages of dense French prose. Whoever goes through that experience, however, will not be disappointed and will appreciate the intricate philosophical questions that the ancients were dealing with.

The questions and evidence first examined by astrology are deceptively simple: Why, for example, do seeds germinate only during the spring, and why do leaves fall in the autumn? Were these phenomena caused by the Sun, which was believed to rotate around Earth? Since the Sun's yearly path coincided rather well with events in spring and fall, could the other planets and the Moon have similar effects?

For the venerable Aristotle and his followers, who laid the intellectual foundations of astrology, all the manifestations of change—in particular, those of coming-to-be and decay—are the by-products of cyclical motions of the celestial bodies and the inclination of the solar path. This inclination, or ecliptic, along and around which all the other planets also seem to move (adjusting for the effects of the planets themselves), would later be elaborated on by Ptolemy. Once the celestial and the earthly realms were connected, it was a relatively small step to use this process to answer such elusive questions as, What kind of life will a child turn out to have? Lucky and wealthy, or destitute? And if it is the latter, could one take any steps to avert this destiny? The answers that succeeding generations provide to such questions are worth studying for what they say about the social history of an era.

Whitfield is right to conclude that the "rationalization" of astrology (using it to make unverified cause-and-effect connections similar in structure to the ones usually made in a scientific statement) took place at the hands of the Greek philosophers, especially Aristotle. Subsequently, Ptolemy formulated astrology as a natural system, a set of physical laws operating without any reference to the mythological gods of Greek antiquity. But Whitfield does not note that astrology's rationalization by the Greeks almost five centuries later is nowhere free of the mythological substratum upon which it was erected. Otherwise, why would Ptolemy (as well as modern astrologers) ascribe to the planet Mars all the maleficence pertaining to the Greek god of war and bloodshed, and to the planet Venus all the beneficence pertaining to the Greek goddess of love and romance?

The fact that astrologers tried their very best—and still do—to cloak their discipline in complicated mathematical constructions does not validate it as science. It is true that the computation of the point of the Sun's path that happens to be rising over the eastern horizon at a specific moment (a point called the horoscope or the ascendant in astrological parlance) is indeed a rather sophisticated exercise in spherical trigonometry. But its significance for the kind of life a child will turn out to have is speculation. Modern defenders of these computations assert that science cannot answer a whole host of questions—but neither can astrology or, for that matter, magic, geomancy, palmistry, or sheer guessing.

George Saliba, a professor in the Department of Middle East and Asian Languages and Cultures at Columbia University, is the author of numerous publications and books, most recently A History of Arabic Astronomy: Planetary Theories During the Golden Age of Islam *(New York University Press, 1994).*

nature.net

Jumping Genes and More

By Robert Anderson

When it comes to teaching science, the Internet has one clear advantage over textbooks: it can incorporate a full range of media to bring lessons to life. One of the best examples I have found is DNA From the Beginning, a site produced by the Dolan DNA Learning Center at Cold Spring Harbor Laboratory in New York (vector.cshl.org/dnaftb/). Billed as "an animated primer on the basics of DNA, genes, and heredity," the site is also a wonderful place to learn about the men and women who made the key discoveries. This is not surprising, given the laboratory's central role in much of that history.

The primer presents forty-one concepts, each including a video interview with a scientist, biographies of the important players, a gallery of relevant photos, a problem, and links for further study. But what most impressed me were the animated clips that illustrate the concepts. They require Flash Player to view, but seeing the molecules in motion makes it much easier to understand what is going on. Without a doubt, genetic information is dynamic. Take concept 32, "Some DNA can jump." The animation shows how, in Barbara McClintock's famous experiments with corn, genes can flip from one part of a chromosome to another.

Although some may find certain concepts challenging, the history that accompanies them is fascinating enough to keep one reading. If you've never read James D. Watson's 1968 classic, *The Double Helix,* concept 19 is a must. You'll get a fantastic, concise explanation of how Watson and Francis Crick (with some help from others) figured out the twisted ladder shape of DNA.

Robert Anderson is a freelance science writer living in Los Angeles.

BOOKSHELF

The Birds of Heaven: Travels With Cranes, *by Peter Matthiessen; paintings and drawings by Robert Bateman (North Point Press, 2001; $27)*
In many cultures, cranes are regarded as symbols of longevity, good fortune, and harmony. Matthiessen journeys from Mongolia and Siberia to Sudan and South Africa to track the dwindling populations of the world's fifteen species of cranes.

The Monkey in the Mirror: Essays on the Science of What Makes Us Human, *by Ian Tattersall (Harcourt, 2002; $25)*
Writing in a lively, engaging style, American Museum of Natural History anthropology curator Tattersall muses on the nature of science and the multifarious processes of evolution, raising a host of intriguing questions about the biological and cultural histories of our own hominid family.

Darwin, His Daughter & Human Evolution, *by Randal Keynes (Riverhead Books, 2001; $26.95)*
Keynes, a great-great-grandson of Charles Darwin, found—in a chest of drawers inherited from his grandmother—the memorabilia-filled writing case of Darwin's beloved daughter Annie (who died at age ten). The discovery prompted him to write about Darwin's home life and the personal experiences that shaped his deepest ideas.

The Bone Museum: Travels in the Lost Worlds of Dinosaurs and Birds, *by Wayne Grady (Four Walls Eight Windows, 2001; $24.95)*
Grady, former science editor for the magazine *Equinox*, chronicles his travels with Canadian vertebrate paleontologist Philip Currie to dig for fossils on three continents. The author gains insight into not only the nature of evolution but also the drudgery and frustration of fieldwork.

Coming Home to Eat: The Pleasures and Politics of Local Foods, *by Gary Paul Nabhan (W. W. Norton, 2001; $24.95)*
Nabhan, director of the Center for Sustainable Environments at Northern Arizona University, devoted a year to eating only foods grown or caught within 200 miles of his home.

Aging Well: Surprising Guideposts to a Happier Life From the Landmark Harvard Study of Adult Development, *by George E. Vaillant (Little, Brown, 2002; $24.95)*
In an unprecedented series of studies, Harvard Medical School has followed 824 subjects—men and women from different economic backgrounds—from their teens to old age. Vaillant, the project's director, uses these studies to illustrate the variables involved in reaching a happy, healthy old age, explaining how natural resilience is affected by lifestyle choices and by factors such as marriage, divorce, and negative personality changes.

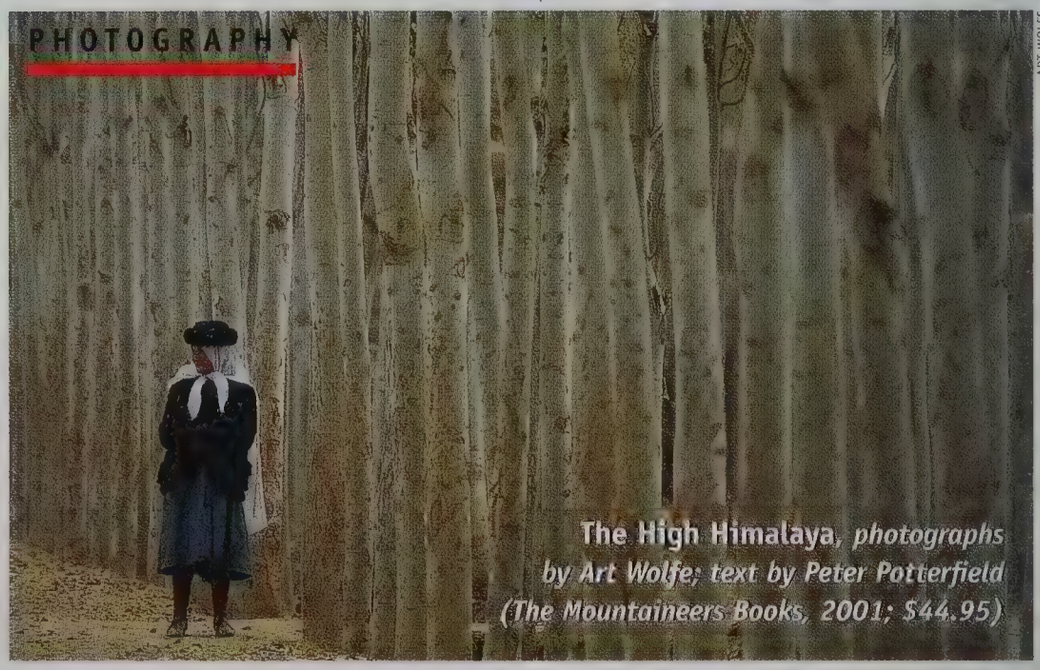
The Aging Brain, *by Lawrence Whalley (Columbia University Press, 2001; $22.95)*
As scientists tease apart the influence on the brain of environmental (diet, stress) and biological (genes, brain injuries) factors, they are developing a range of therapeutic and preventive measures that can help ensure the sustained vitality of our mental faculties.

Origins: The Evolution of Continents, Oceans and Life, *text and photographs by Ron Redfern (University of Oklahoma Press, 2001; $49.95)*
This unique survey of Earth—the formation and movements of its landmasses, seas, and mountains, as well as the emergence of its inhabitants—includes not only breathtaking photographs and excellent illustrations but also highly readable commentaries by a pioneer of, and authority on, interpretive landscape photography.

What Evolution Is, *by Ernst Mayr (Basic Books, 2001; $26)*
Largely responsible for shaping the modern synthesis of genetics and evolutionary theory, Mayr—now ninety-six and still professionally active—has written an elegant primer on evolution, in which he gives a spirited defense of Darwinian explanations of biology.

The books mentioned are usually available in the Museum Shop, (212) 769-5150, or via the Museum's Web site, www.amnh.org.

PHOTOGRAPHY



ART WOLFE

The High Himalaya, *photographs by Art Wolfe; text by Peter Potterfield (The Mountaineers Books, 2001; $44.95)*

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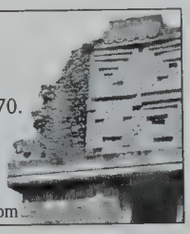

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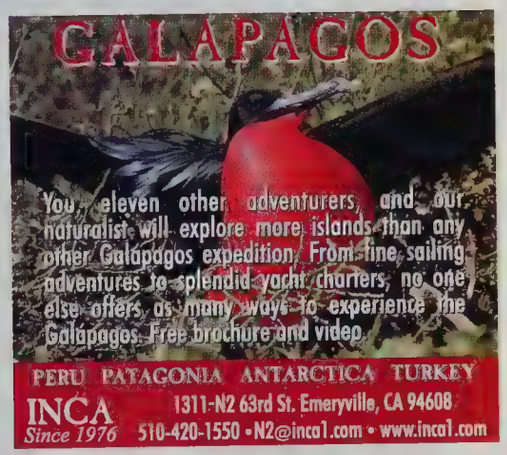
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ENDPAPER

FLAG WAVING

By Michel Pastoureau

In the Western world, the wearing of stripes originally constituted a handicap or liability. Medieval society, literature, and iconography endow a great number of individuals—real or imaginary—with striped clothing. In various ways they are all outcasts and reprobates: ranging from the heretic to the clown, the gamut includes not only the leper, the hangman, and the prostitute but also the disloyal knight of the Round Table, the madman of the Book of Psalms, and the character of Judas. They all disturb the established order; they all have more or less to do with the devil.

At the end of the Middle Ages, stripes make a very rapid transition from the diabolic to the domestic (though perhaps retaining their old connotation of impurity) and gradually become the sign of a servile condition or subordinate function, such as that of a lord's household staff. Parallel to the development of the domestic stripe is the evolution of another category—the aristocratic stripe, sometimes sophisticated, always in good taste. This stripe triumphs during the second half of the eighteenth century, the first period of romanticism and revolution.

ATTRIBUTED TO STUDENT OF GIOTTO, CA. 1340, SAN DOMENICO CHURCH, BOLZANO, ITALY

The ignominious stripe: In a fourteenth-century mural, three young women are saved by Saint Nicholas from a life of prostitution.

In the late 1770s a rage for stripes is found among the Americanophiles in France and in other countries hostile to England. The American Revolution was an offshoot of the Enlightenment; the flag, with the thirteen red and white stripes for the thirteen American colonies rebelling against the British crown, appears as the image of Liberty and the symbol of new ideas. The stripe quickly acquires an ideological and political status: wearing it, adorning oneself with it, displaying it at home or outside can proclaim one's Anglophobia or one's support of the movement for freedom. But it also becomes, quite clearly, a fashion trend.

Everywhere on the continent, there is an unfurling of stripes. Dresses, jackets, jerkins, coats, frock coats, waistcoats, petticoats, blouses, stockings, pants, trousers, aprons, ribbons, scarves: as much in court as in villages, most pieces of clothing are, or can be, striped. The aristocratic stripe and the peasant stripe meet up with each other and sometimes merge, as in the country and shepherd scenes of which painters and engravers have left so many examples. This rage for stripes lasts more than half a century, involving all social classes. Gradually the fashion in stripes extends to fabric for interiors and furniture.

It is difficult to say precisely why the French Revolution made such wide use of stripes and striped surfaces, to the point where they end up in its emblematic repertoire side by side with the fasces, the pike, the tricolor rosette, and the liberty cap. For two centuries, in paintings, engravings, picture books, theater—and later in film, television, and comic strips—all Revolutionary decor is striped decor, and every patriot or sansculotte is a figure wearing striped pants or vest.

Is it going too far to see in the French Revolutionary stripe a vestige of the image of the devil, juggler, or madman, all transgressors against the established order? Is it going too far to establish an *a posteriori* connection, at once dreamlike and geometric, between the bars of the Bastille, those prisons of the Reign of Terror, and the striped clothing so prized by the men of the French Revolution?

At the end of the eighteenth century, however, the Revolutionary stripe is neither a creation nor a monopoly of the French. Having come from America, it retains—even up to our own times—its American connotation.

Michel Pastoureau is an authority on medieval heraldry and a professor of history at the Sorbonne. He is also the author of Blue: The History of a Color *(Princeton University Press, 2001).*

Adapted from *The Devil's Cloth: A History of Stripes & Striped Fabric,* by Michel Pastoureau; translated by Jody Gladding. Translation and preface copyright © 2001 Columbia University Press. Copyright © 1991 Editions du Seuil. Reprinted with permission of the publishers.

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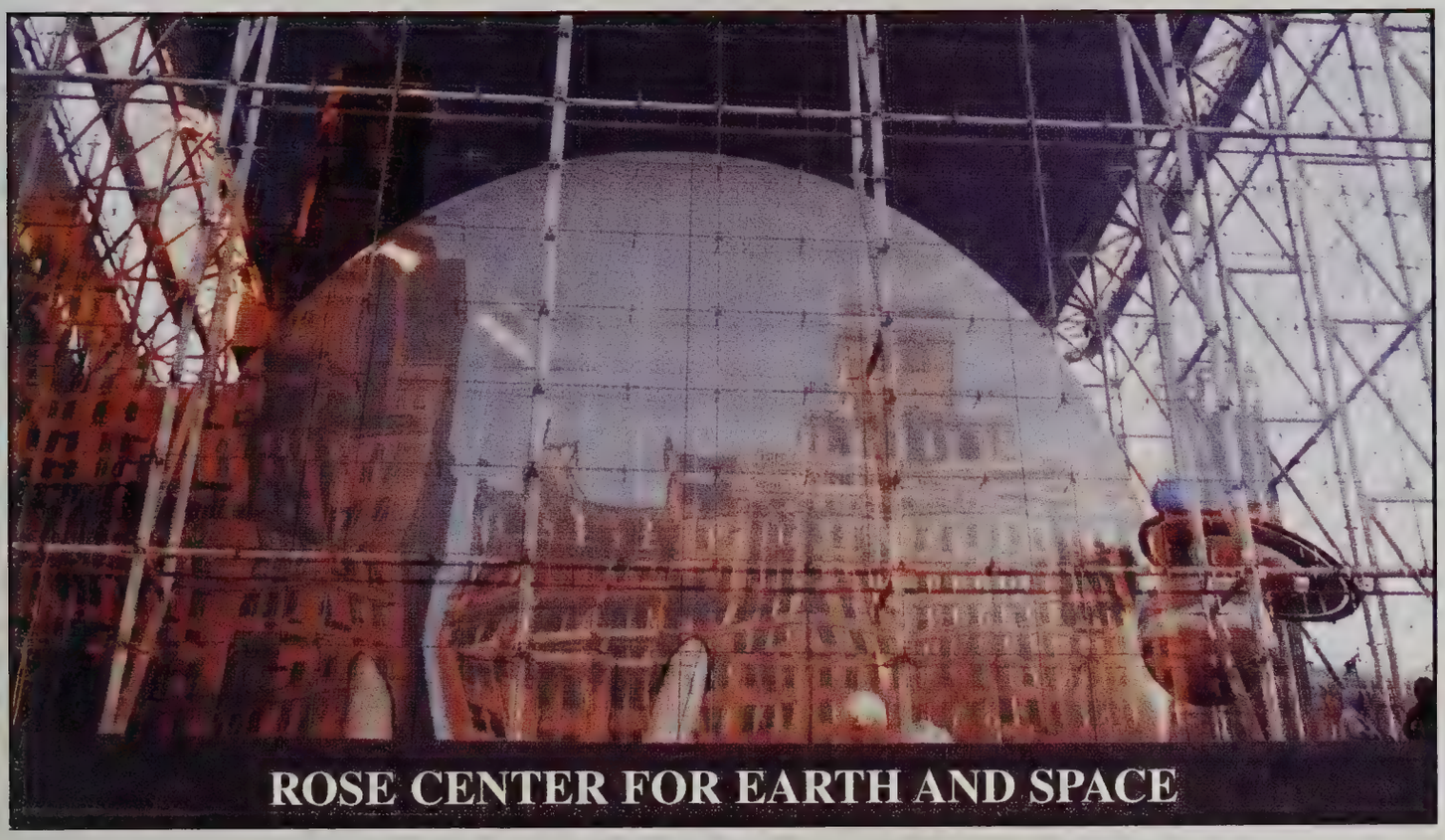

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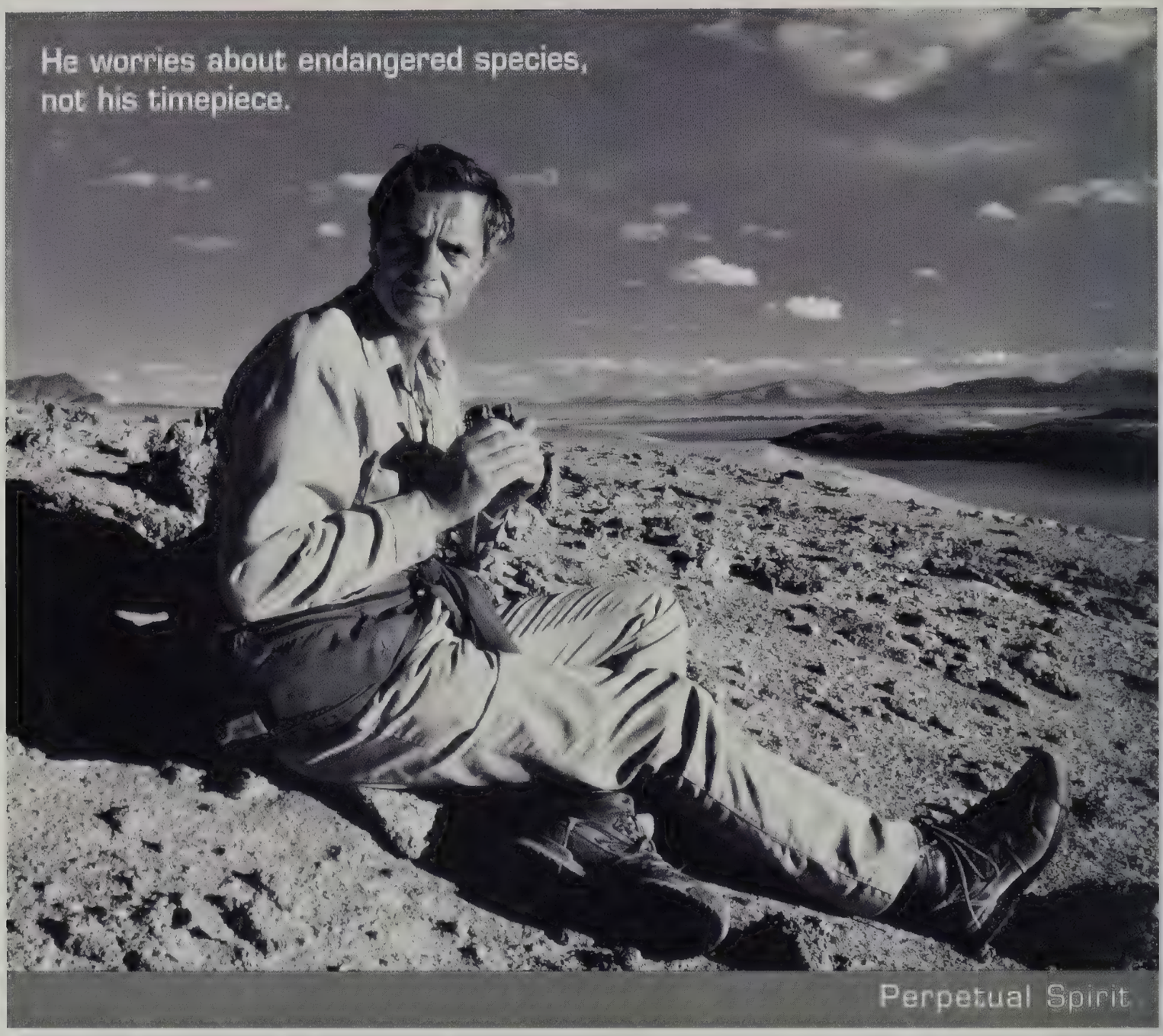

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